ESTABLISHED
1865

THE NORWALK AIR COMPRESSOR

The Norwalk Iron Works Co.
SOUTH NORWALK,
CONN.

THE NORWALK
AIR COMPRESSOR.

CORRECT IN THEORY. SUPERIOR IN PRACTICE.

RECOGNIZED AS THE HIGHEST STANDARD BY SKILLED ENGINEERS AND USED BY THE MOST EXPERIENCED OPERATORS.

The Best Machine for Compressing Air for all Dynamic Purposes.

ESPECIALLY DESIGNED FOR DRIVING COAL CUTTERS, ROCK DRILLS, PUMPS, ENGINES, PNEUMATIC LOCOMOTIVES, AND FOR MINING

Fully Protected in all Important Details of Construction by U. S. Patents already issued or now under application.

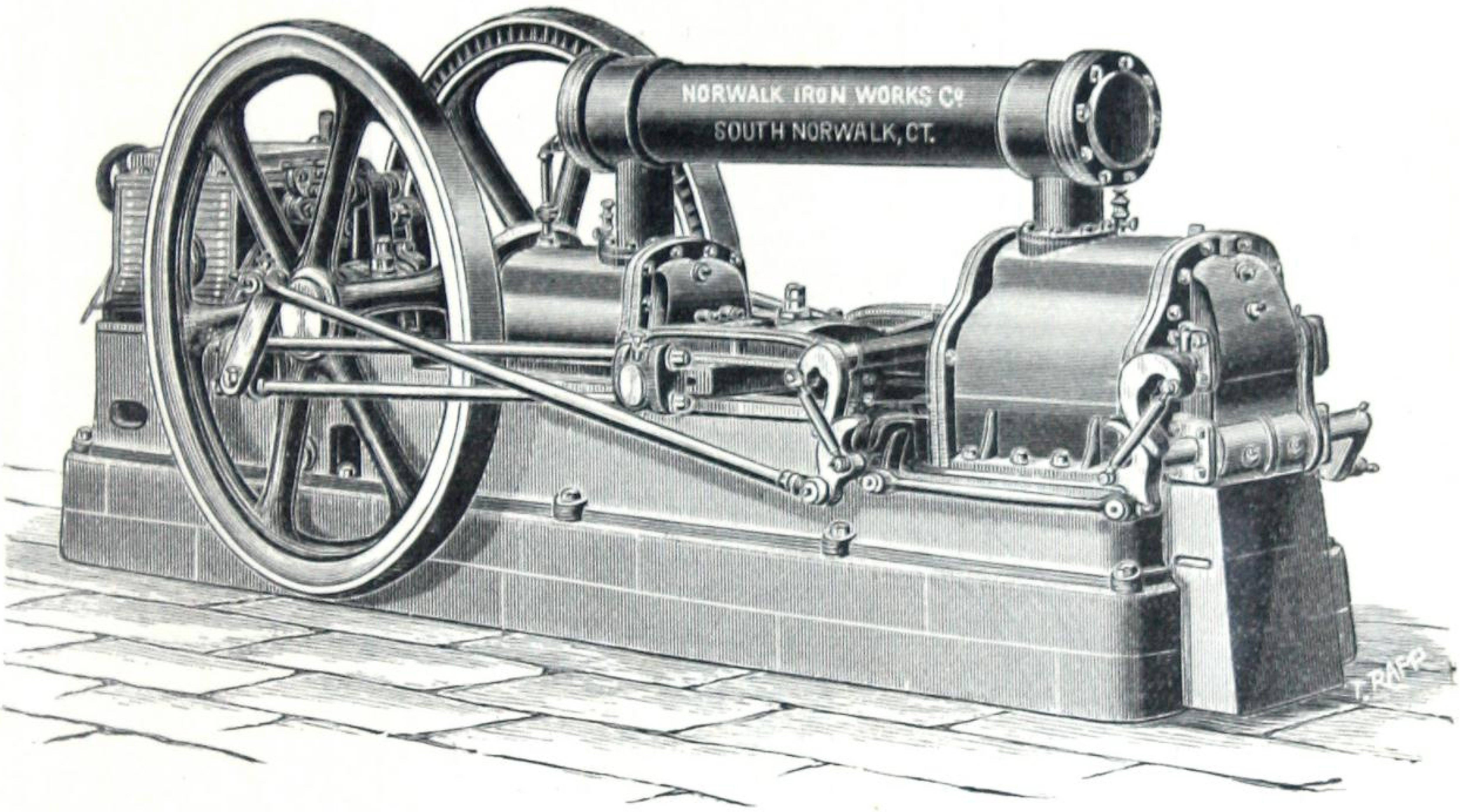
MANUFACTURED BY

The Norwalk Iron Works Co.

South Norwalk, Connecticut

1889.

GENERAL INDEX ON THE LAST PAGE OF THE BOOK.



The Norwalk Air Compressor.

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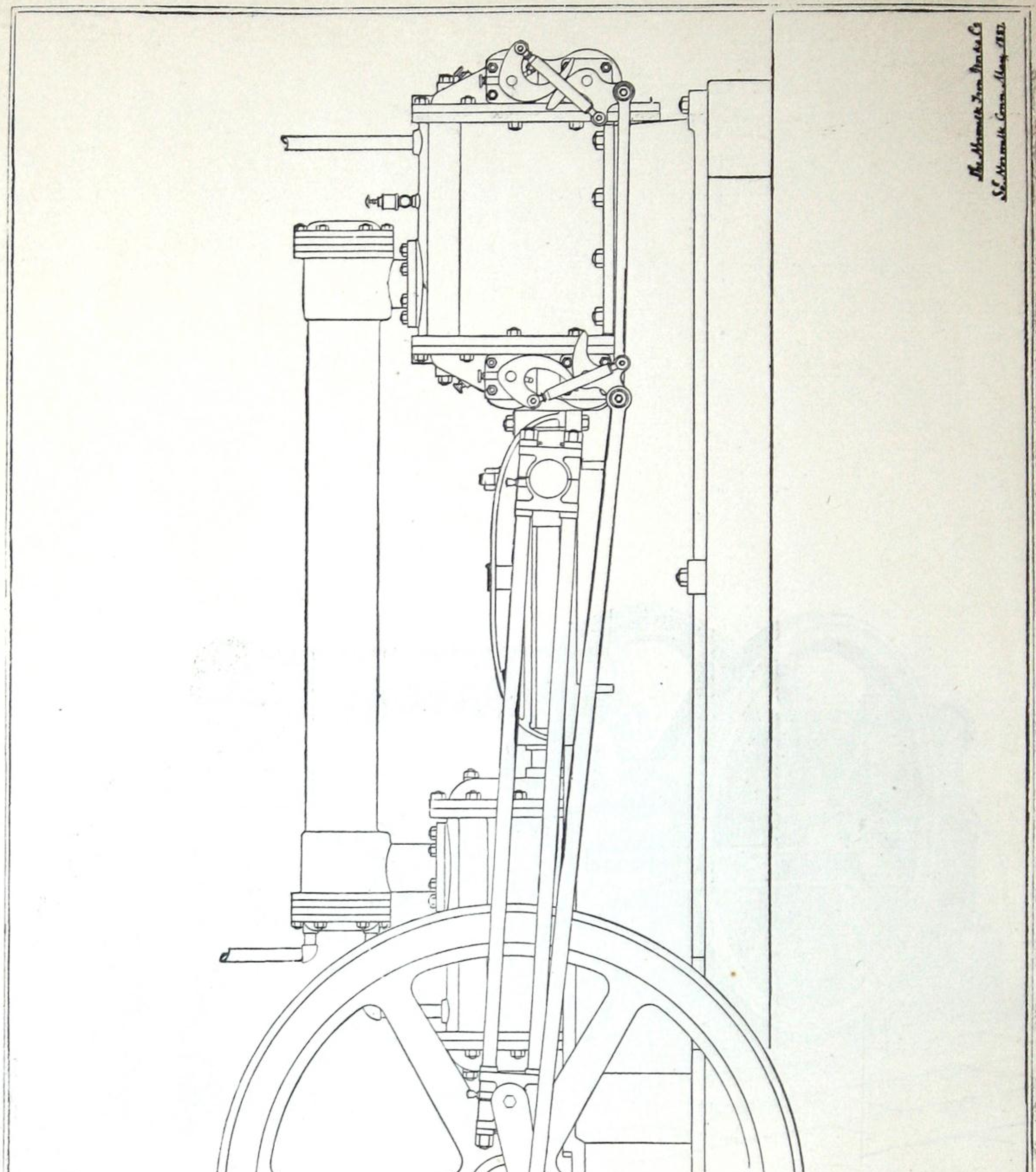
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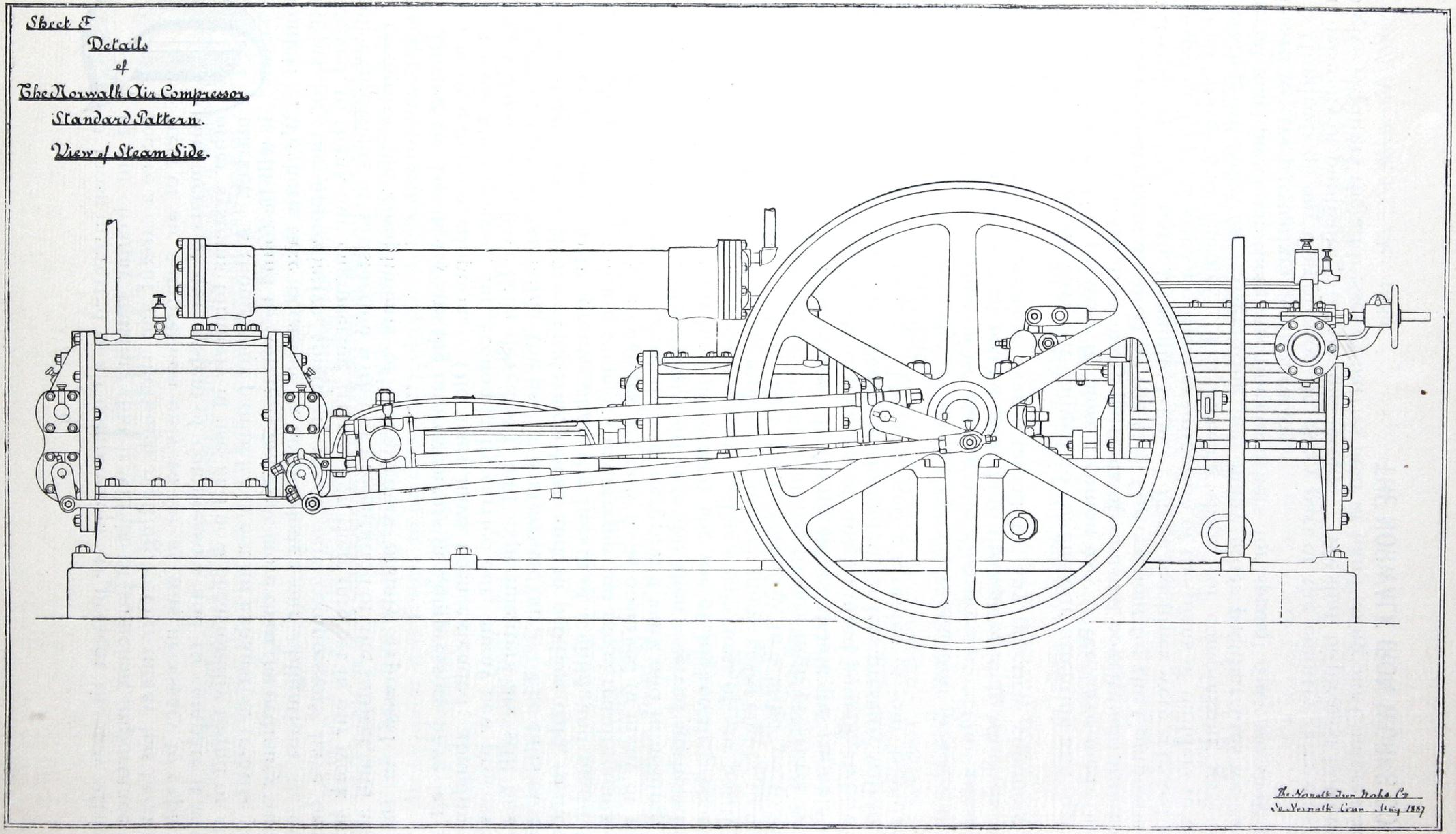
View of Exhaust Side.
The Norwalk Iron Works Co
So. Norwalk Conn. May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The Norwalk Iron Works Co
So. Norwalk Conn. May 1887

TO those interested in air compression, we present the new edition of our circular, trusting that it will be of sufficient importance to secure a careful and thorough reading. Our intent has been to treat of air compression only so far as was necessary to explain the merits of our system of compressors and to compare it with other systems formerly in use and now occasionally found on the market. Although our pamphlet is not an exhaustive treatise yet it will be found to contain somewhat more than the ordinary trade circular. We here take occasion to acknowledge our obligations to our patrons for the appreciative spirit in which our compressors have been received, to thank our engineering friends for their interest in our work and their expressions of satisfaction with our presentation of the subject, and also to recognize the compliments of competitors plainly expressed in their attempts at imitation.

During the last few years the improvements in Compressors have led to their more extensive adoption. Old uses have been extended; abandoned plans have been revived, and economically carried out; many new processes, using Compressors, have been developed, and experimenters are still busily engaged in further extending the use of compressed air. The calls on the designer have been varied. To develop heat, and to produce cold, to move the air with a force hardly greater than the breath of a child, and again to blow a shot from a cannon, are some of the extreme and novel requirements of our Compressors. Notable changes are now to be observed in many of the old and familiar methods of using air in underground work and in mining.

A few years since, directly in opposition to the then received authorities, we pointed out the economy, and advocated the use of higher air pressure, when pipes were used for its conveyance. The correctness of our position has been proven by numerous examples, and in very many cases eighty to one hundred pounds pressure is now used where formerly, in similar positions, forty to fifty pounds was the limit. The tendency toward high pressures is so marked, that for furnishing power all Compressors should be capable of continuous economical work at air pressure of one hundred pounds and over, with ordinary steam pressures. Machines intended for less pressure will soon be placed at a disadvantage. The test and guarantee of our Standard Machines cover these requirements.

For special work we are ready to contract for any reasonable pressure that can be utilized or governed after leaving the Compressor. Our present experience extends to five thousand pounds to the square inch, which is, we believe, the highest air pressure ever attained by any practical commercial machine.

In this pamphlet we have felt obliged to confine our attention and space to the varieties of Compressors in most common use. We have made and have now under construction many patterns of unusual novelty and interest. Our designs have been adopted by the U. S. Government for the Compressors used with the Pneumatic Dynamite Guns. These machines were selected by a Board of Experts after a critical examination of the plans of builders in the United States and Europe. For steering ships, for compressing gas, for operating ordnance, for refrigerating and many other peculiar uses we have special machines. Of these machines or others for special duty we shall be pleased to give particulars on application.

Hundreds of our Compressors in every part of the country relieve us of the necessity of publishing "testimonial letters." We shall be pleased, however, to give inquirers the addresses of parties near at hand using our Compressors.

South Norwalk, Ct., Dec. 1889. THE NORWALK IRON WORKS CO.

Early Patterns.

For over twenty years the compression of air has been a study with us and machines for the purpose have been a considerable portion of our product.

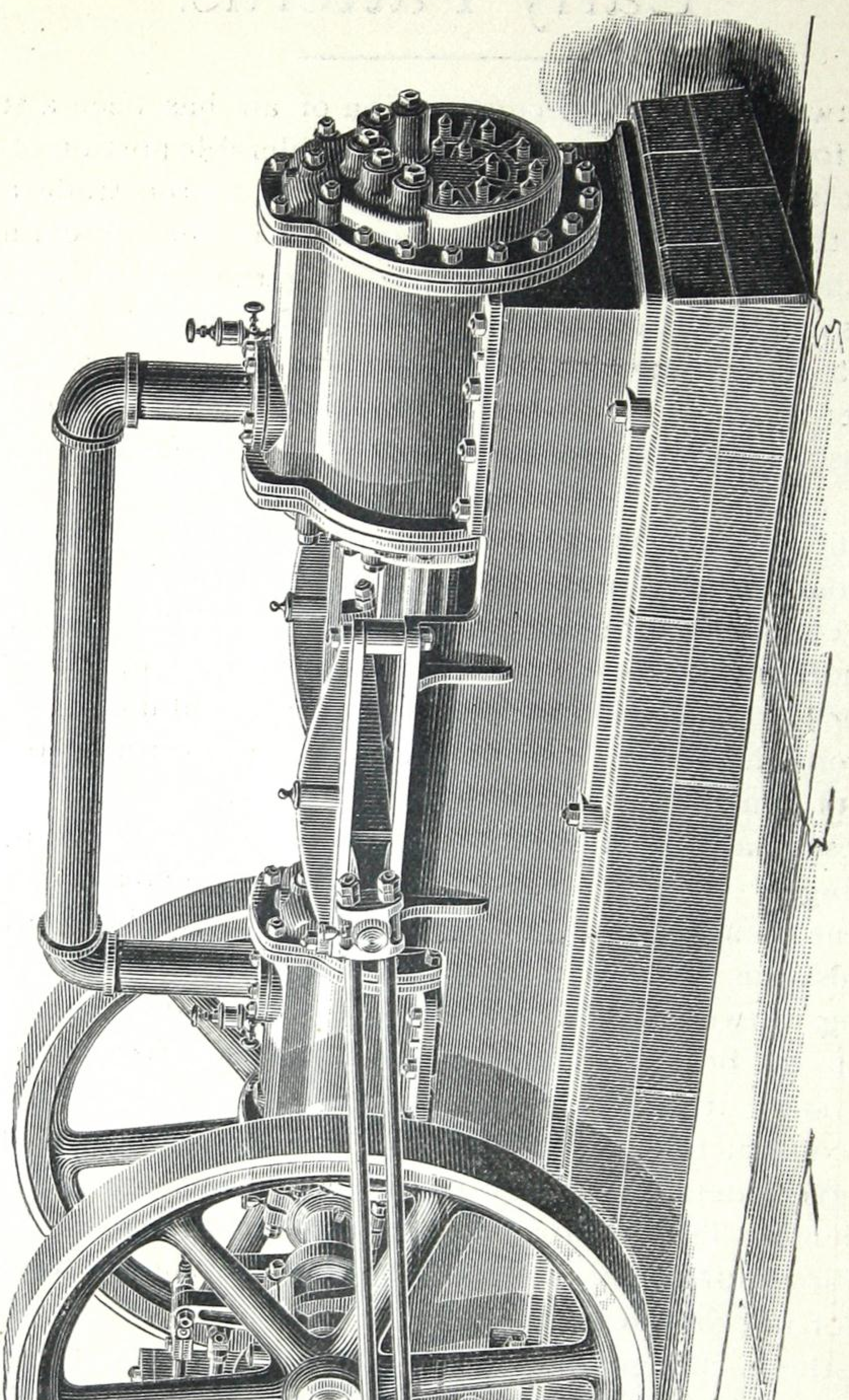
Our earliest patterns were what are known to the trade as "wet compressors," for the reason that water was used in the air cylinder in direct contact with the air for the purpose of cooling the air during compression. The water was at first introduced in a stream with the air; next it was injected as a spray by a pump. In whatever way it was used, the presence of water in the air cylinder was found to be extremely objectionable, for mechanical and theoretical reasons which are referred to at greater length on another page of this circular.

After sufficient test we abandoned the "direct contact system," and effected all cooling by surface cooling only, employing water jackets on cylinder and cylinder heads, and circulating water through the piston by means of a hollow piston-rod. This plan was far superior to the other. However, after test, it developed its peculiar disadvantages. The water was then taken from the piston, at a sacrifice of some desirable points it is true, but at a gain of some features still more necessary.

In all these machines the inlet and outlet valves were "poppet valves," closed by springs. The general arrangement was a steam cylinder and air cylinder in line on a bed plate, or having a body piece between them, a long crosshead across the widest part of the machine, and connecting rods on each side, extending to two crank fly wheels on a shaft parallel to the crosshead. At this point we began the development of the Compound Compressor. At the very start it was the embodiment of a ripe experience in Air Compressor construction. All desirable features of former patterns were retained and every detail thoroughly studied and improved in every way that was then evident. The machine at once took the first rank. Yet a constant watch over all requirements and possibilities has shown from time to time many places for improvement.

Some of these changes may be of interest, and their illustration may perhaps be of assistance to a full understanding of the construction of the Norwalk Compound Air Compressor.

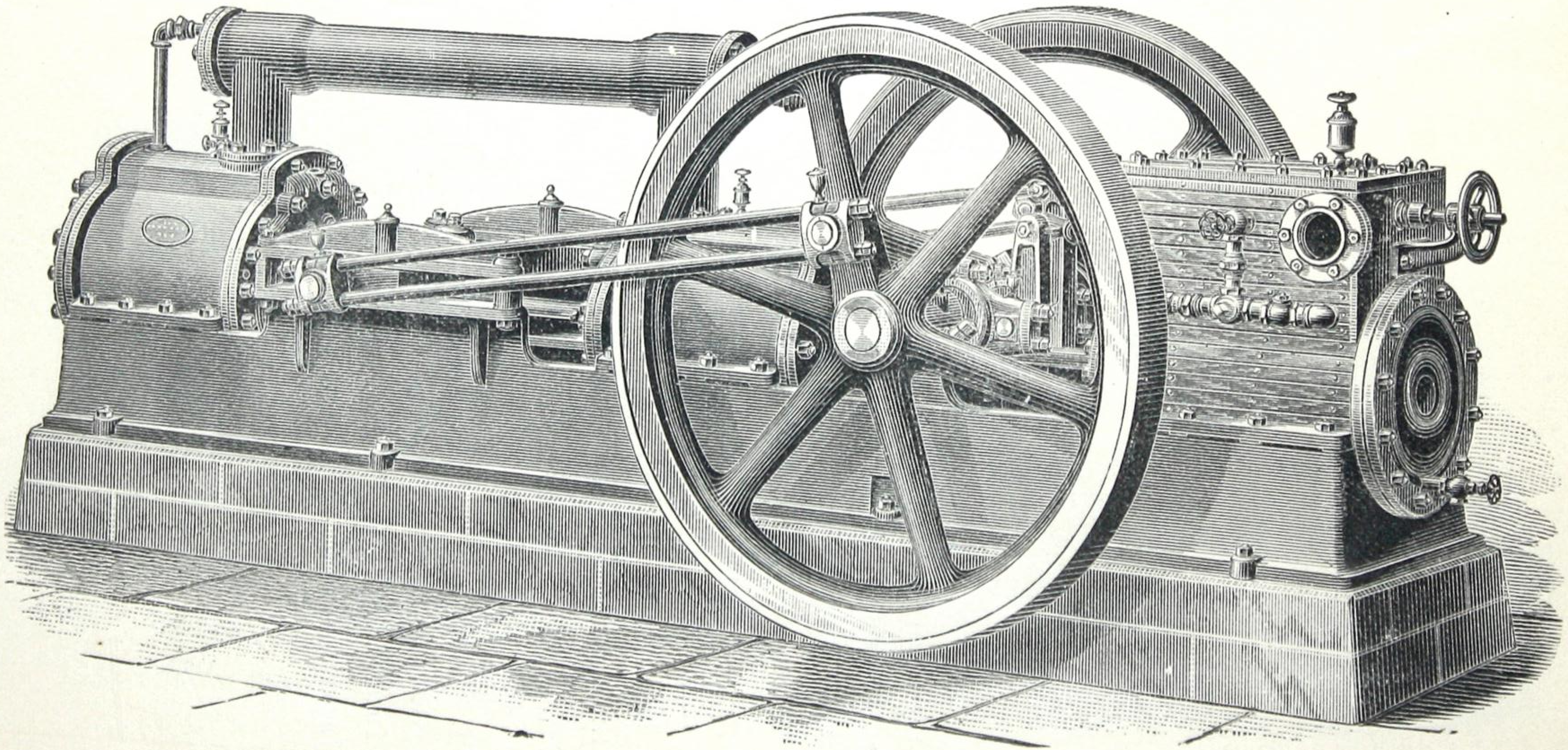
We therefore illustrate the patterns made since 1880. The brief notes opposite each cut, together with a more extended description in the following pages, will serve to show the more important features of our Compressors. There are also very many minor details of the machines in which our practice differs from usual patterns. To illustrate these would make our circular too bulky. We would say, however, that in every case we have substantial reasons for each particular form of construction, and have adopted the designs and the materials which experience has shown to be the best as our standard.



Pattern of 1880.

Pattern of 1880.

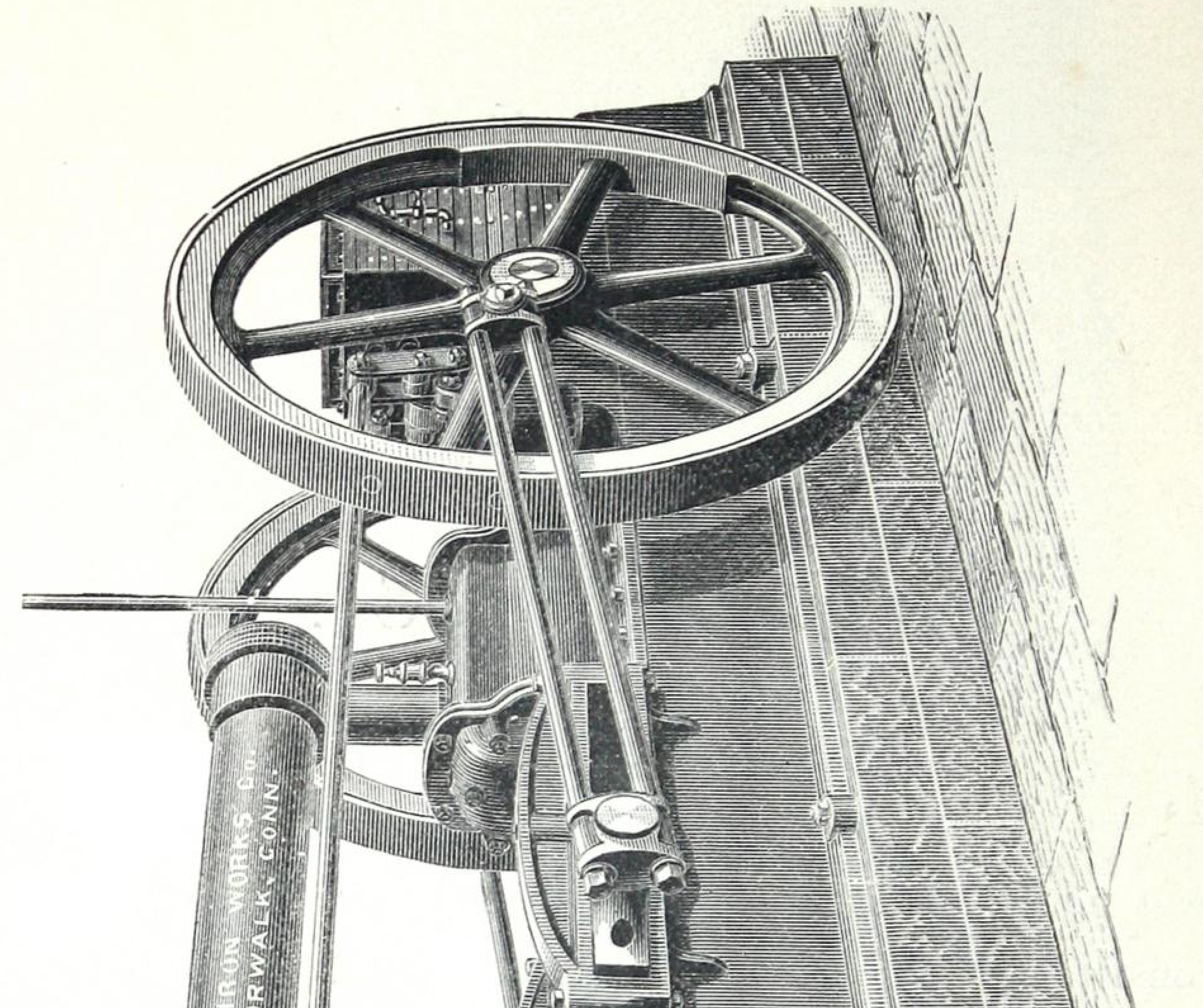
The cut on opposite page illustrates the Compound Air Compressors as constructed in 1880, with Steam and Air Cylinders of 20 inches diameter and 24 inches stroke. The Compressing Air Cylinder is shown between the steam and Intake Air Cylinder and is 13½ inches in diameter. The air valves were of the Poppet variety, of the most approved construction and very liberal in area. Both air cylinders were provided with Water Jackets. The air was taken into the large cylinder. It was there partly compressed and thence conducted by a large pipe to the smaller compressing cylinder, where it was compressed to the desired pressure. The objects aimed at in this construction, were, first to make the resistance of the air to compression an average resistance throughout the stroke, instead of the excessive and maximum resistance at the end of the stroke, which is obtained in all Single Compressors; secondly, to reduce the losses of clearance spaces to the smallest amount by having the pressure in the Intake Cylinder a light pressure; third, to have the advantages of two Water Jackets and more time for cooling the air.



Pattern of 1881.

Pattern of 1881.

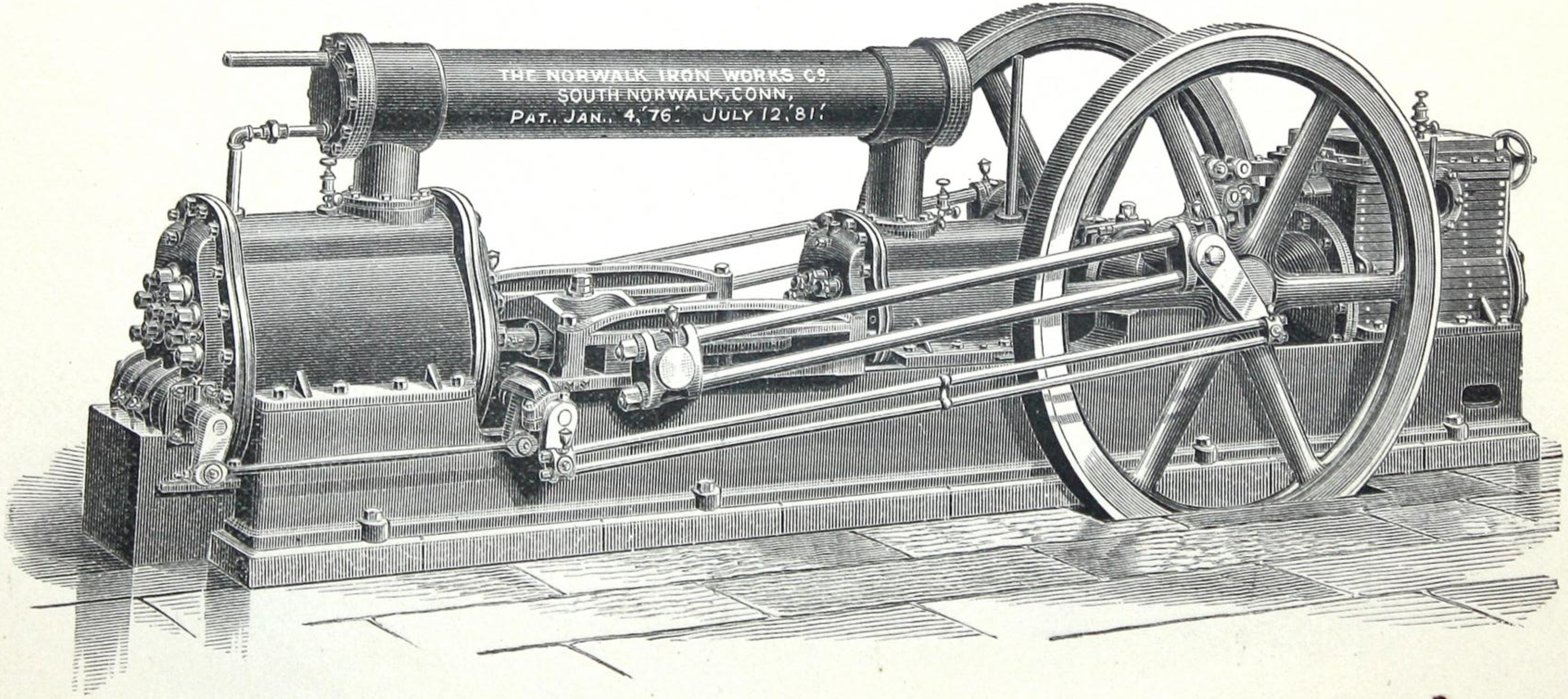
In this was added an Intercooler between the two Air Cylinders. This Intercooler consists of a large pipe or reservoir filled with thin brass water pipes. The air in its passage to the second cylinder becomes divided into thin streams by the water pipes, and thus each particle is brought into contact with a cold surface and its temperature rapidly reduced. Here is also shown the Hand Wheel for varying the point of steam cut off, which can be adjusted to suit circumstances, while the machine is in motion. By Pass Valves for convenience in starting without changing cut off point are also shown.



Pattern of 1882.

Pattern of 1882.

Here is shown a "new departure" for Air Compressors. The Poppet Inlet Valves are removed and one Inlet Valve of the well-known Corliss Steam Engine Pattern is placed in each head of the Intake Cylinder. This improvement does away with much trouble with the little Poppet Valves, and furthermore insures the full supply of air at every stroke. The Valves are opened and shut by a connection with the main engine shaft, and no vacuum or pressure in the Air Cylinder is needed to insure their proper working.



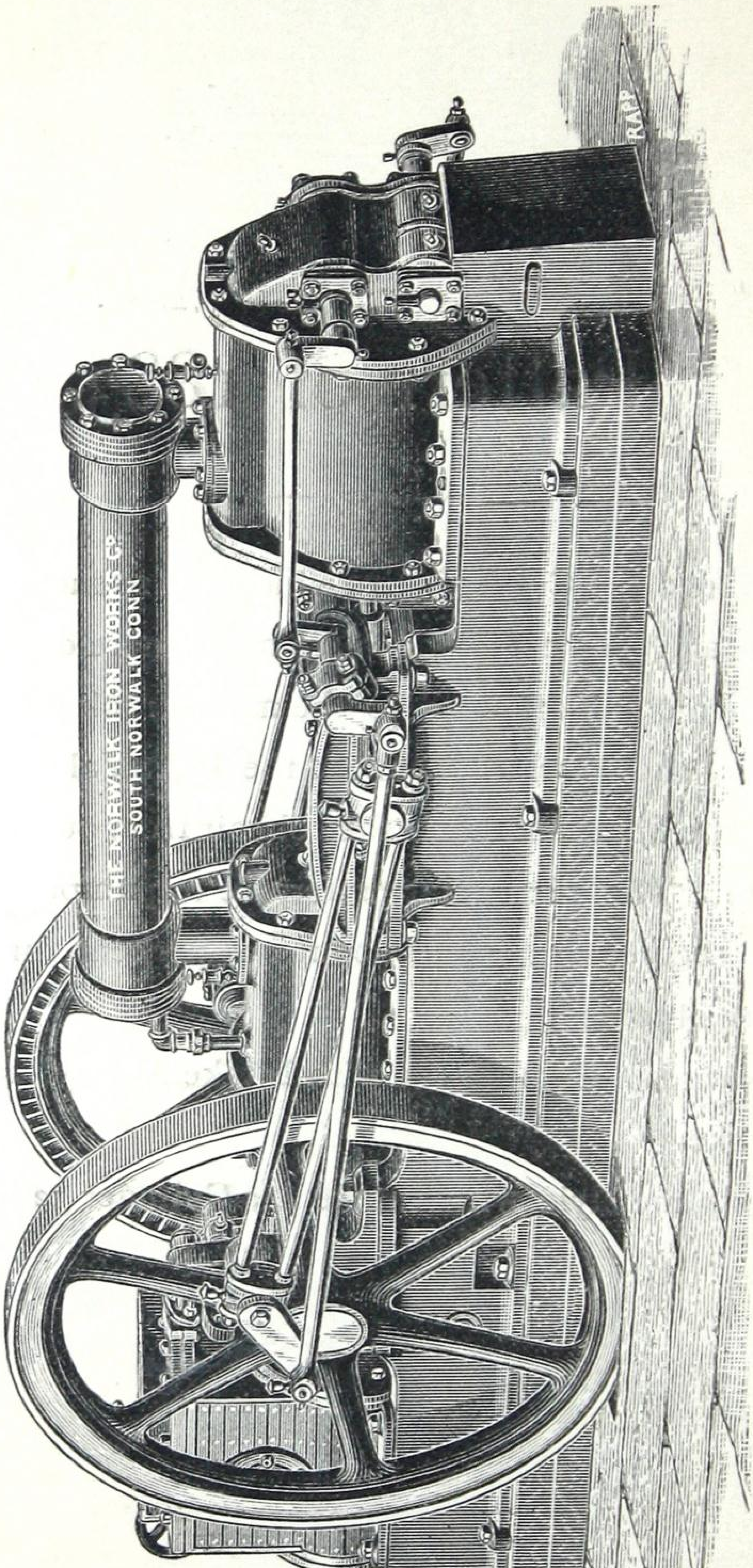
Pattern of 1883.

Pattern of 1883.

In this is retained the Corliss Valve which was so successful in the pattern of the previous year. The connections are made more direct by employing a wrought iron return crank attached to the main crank pin. The removable Air Hoods are here shown which connect the Inlet Valves with the Cool Air Conduit beneath the floor, and leads the cold air from outside the engine room to the Compressor. This plan is far preferable to pumping the hot air of the engine room, and secures a saving of about one per cent. for every five degrees lower temperature obtained.

The cut illustrates a Compressor with Intake Air Cylinder 26 inches bore and 30 inches stroke.

We build this same style with Intake Air Cylinder 32 inches bore and 36 inches stroke.

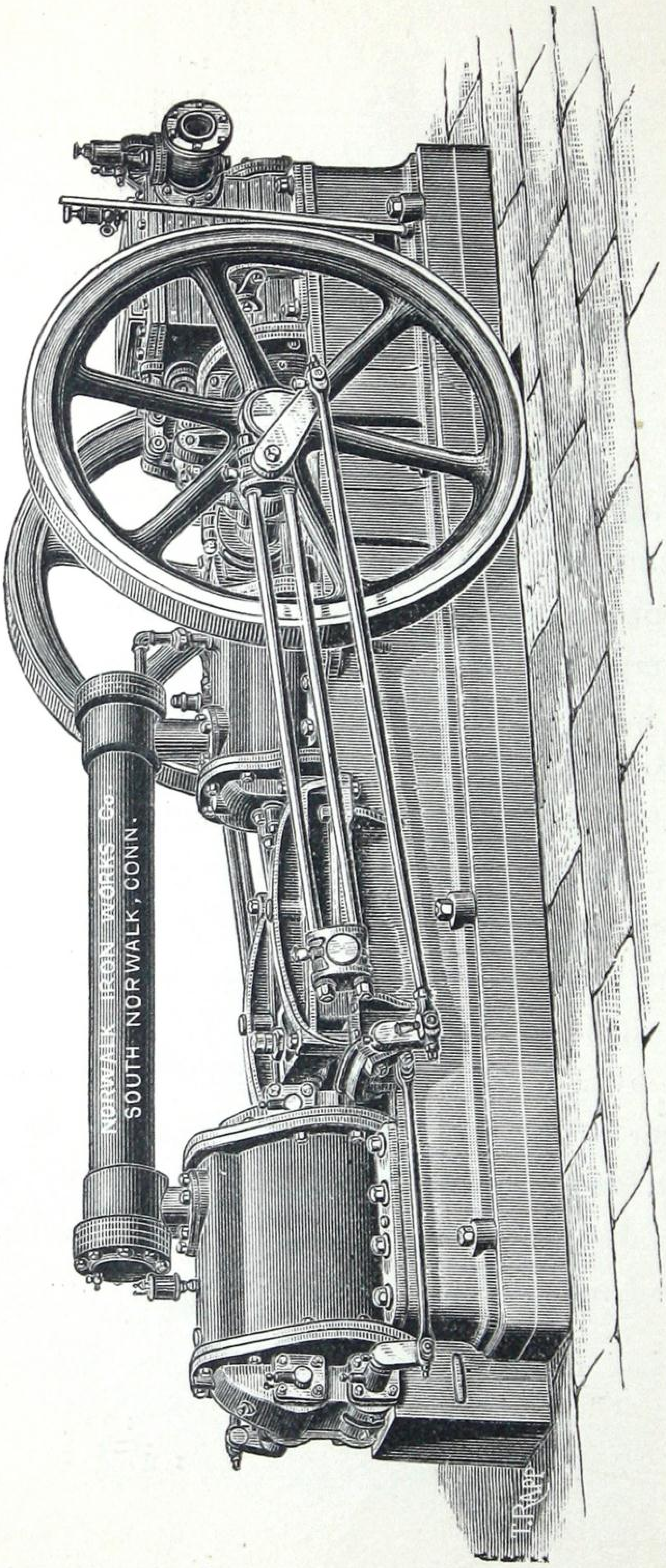


Pattern of 1884.

Pattern of 1884.

The Corliss Valve for admission of air having proved to be such an important improvement, its use was still further extended in the Pattern of 1884, and it was applied as a discharge valve on the Intake Air Cylinder. The amount of compression which is performed in the Intake Air Cylinder is always uniform for the reason that the pressure produced here is simply the pressure required to compress the air into the smaller or compressing cylinder. Hence there being a uniform discharge pressure for this cylinder it is a simple matter to adjust a positive moving discharge valve to open at the exact and proper point of discharge. This arrangement has proved to be highly gratifying and we have adopted it for all our Standard Compressors.

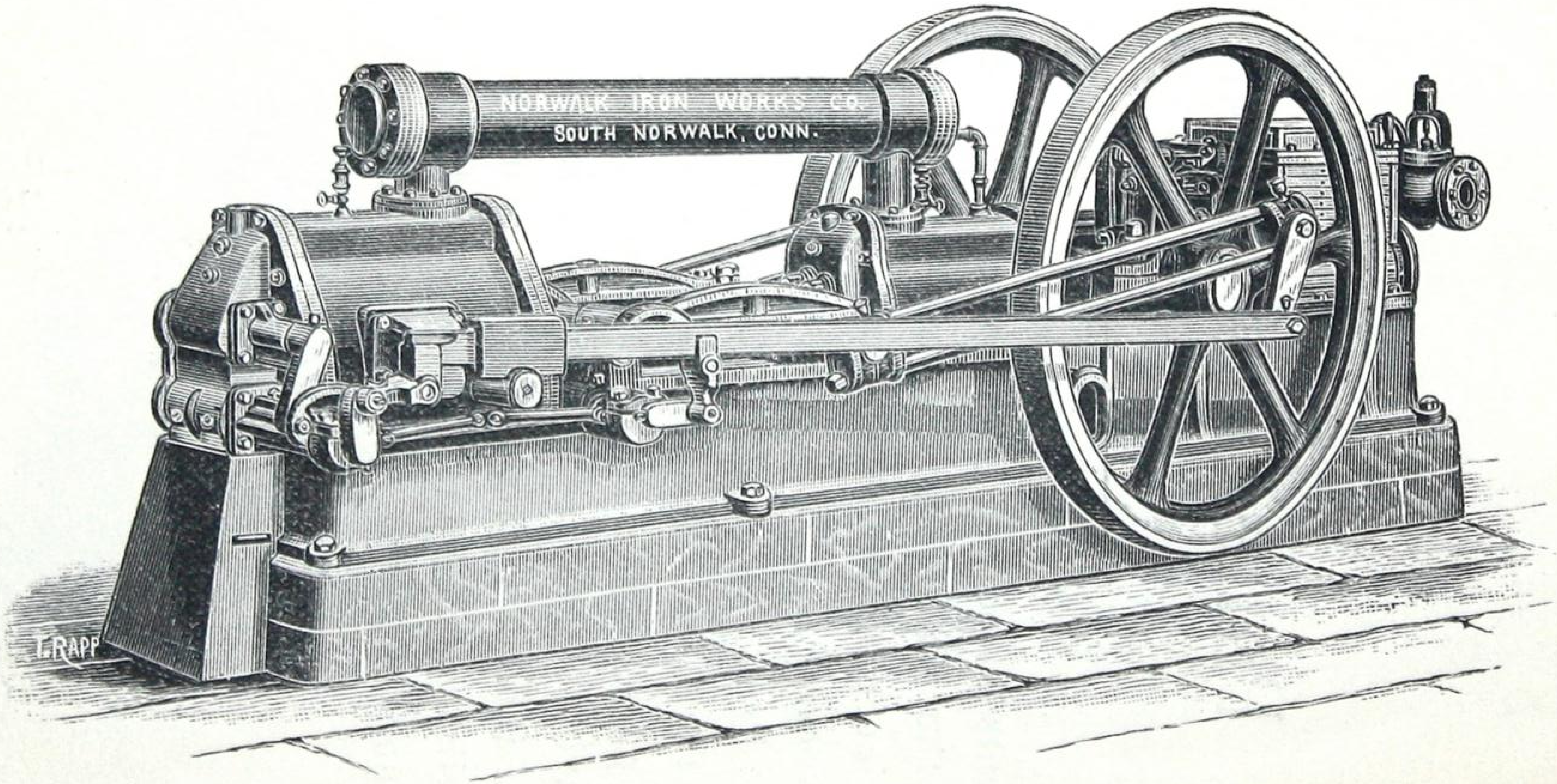
In the cut is also shown, on the inside of the wheel, ratchet notches which are engaged by a pawl when it is desired to move the Compressor by hand. A hand lever is furnished which operates the driving pawl. There is no possibility of the lever or other parts becoming "caught" in the wheels or rods, as the pawl falls away automatically if the lever is withdrawn and is pushed aside if the Compressor is started by the steam.



Pattern of 1885.

Pattern of 1885.

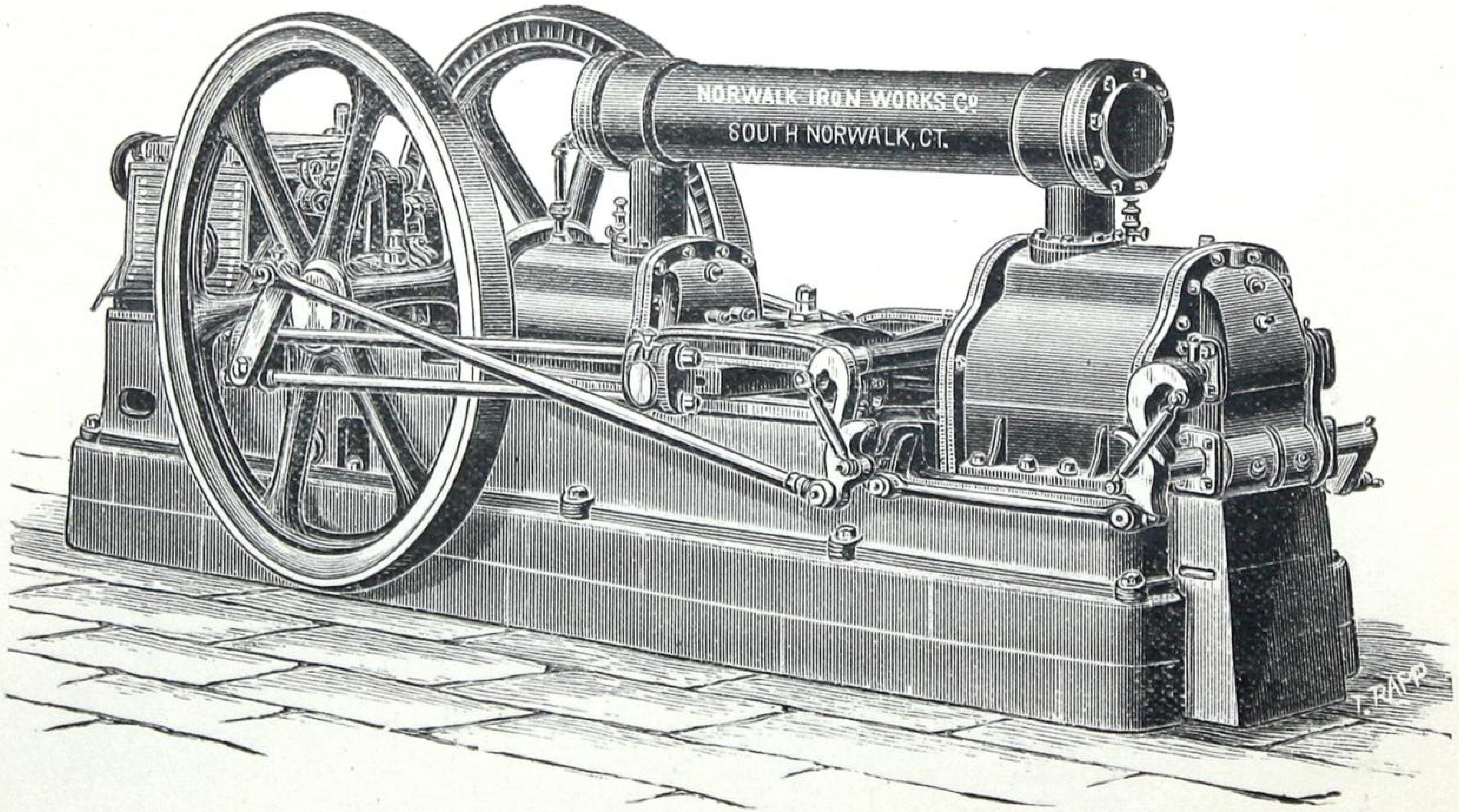
The improvements introduced in this pattern required no alteration in the general features of the machine, but covered many important points in the details, where experience showed that changes might be made either for the betterment of the working of the Compressor or for other advantages to the user. An automatic Pressure Regulator of new and patented design is represented attached to the steam cylinder. This attachment is shown and described in detail on pages 40 and 41. New pattern Lubricators are placed on the air cylinders, having "sight feed" and fine adjustment. The oil drops at any rate desired, at intervals of seconds or minutes. We also again call attention to the Corliss Suction and Discharge Valves. Their more extensive use still further demonstrates their great desirability. We therefore continue their employment.



Pattern of 1886.

Pattern of 1886.

With the year 1886 we enter on the fifth year of use of Corliss Valves on the Air Cylinders. Universal success and satisfaction have attended their employment. In the pattern of 1886 is shown a new valve motion which from its novelty will attract the attention of mechanics. The object of this arrangement is to get the valve motion on one side of the machine and to have the discharge valves stand still during the period that they are closed with more pressure above than below them. We now employ this valve movement on some of our special machines.



Pattern of 1887.

Pattern of 1887.

In the usual patterns of the Standard Norwalk Compresssor the air pressure in the Inlet Cylinder is about 25 pounds. This pressure is so light that we had heretofore considered and found its effect on the wearing of the Corliss Valves of little consequence. However the demand on us for Compressors for pressures to thousands of pounds to the square inch made it expedient to use higher air pressure in our Inlet Cylinder. We thus came nearer to the conditions imposed on those builders who have attempted and failed in making compressors for ordinary pressures with single cylinders and positive valves. Our remedy was effective, and is illustrated in the valve motion of the 1887 pattern. The valves are moved by cams. The shapes of these cams are such that the valve remains at rest until the pressure below it is nearly equal to that above. Then the movement begins and the valve is quickly thrown full open. In closing, the cam allows a rapid movement so that the valve is seated before any considerable pressure comes upon it. The connection which draws it shut is elastic so that if the valve seat is dry no cutting can occur. This form of movement having such desirable features for heavy pressure, is in degree useful on any pressure and we have therefore adopted it for our Standard Compressors.

THE NORWALK
AIR COMPRESSORS

ARE USED IN

Alabama, Arkansas, New York, Pennsylvania, Ohio, Illinois, Indiana, Maine, Missouri, Michigan, Massachusetts, Maryland, Wisconsin, Colorado, Connecticut, Kansas, Iowa, Indian Territory, Kentucky, Texas, New Mexico California, Mexico, Wyoming, New Brunswick, Scotland, Ontario, Washington Territory, Montana, Northwest Territory, Nevada, New Jersey, Central America, U. S. Navy and U. S. Army.

Their Prominent Advantages are

DRY AIR.
HIGH SPEED.
LIGHT WEIGHT.
UNIFORM STRAINS.
FULL AIR SUPPLY.
GREATEST CAPACITY.
UTMOST STRENGTH.
STEAM EXPANSION.
HIGHEST ECONOMY.
COLD INDUCTION AIR.
SMALL FLOOR SPACE.
UNIFORM AIR PRESSURE.
UNEQUALED DURABILITY.
CHEAP TRANSPORTATION.
LEAST LOSS IN CLEARANCE.
INEXPENSIVE FOUNDATIONS.
COMPLETE COOLING ATTACHMENTS.
NO WORKING STRESS ON MAIN SHAFT.
AIR VALVES WITH MECHANICAL MOVEMENTS.

Every possible improvement adopted and used as soon as thorough test demonstrates its desirability.

DESCRIPTION.

One of the first Considerations in planning for the compression of air should be to select that air which is best adapted for the purpose. Ordinarily, however, this is given no attention, and air is drawn into the Compressor directly from the engine room. Such a plan is highly injudicious, inasmuch as such air is rarefied by the heat of the boilers and steam pipes. Vapor of escaped steam is also present, and dust particles are abundant.

***Air should be drawn from outside** the engine room, and from as cool as place as possible. The north side of the building is usually shaded. and a place near the eaves will generally be free from dust. A mine shaft, if close at hand, may frequently supply very cool air in summer if the air conduit is extended in a few feet from the opening. The air may be led to a tight apartment beneath the engine room floor, and here at seasons of the year when water can be had much cooler than air, it should be subjected to a spray to cool it and wash out all dust.

In the Norwalk Compressor provision is made for cold air attachments as described.

*We are the first and only Manufacturers who have recognized the importance of compressing cool air. Under ordinary circumstances air will, after compression and before use, become of the temperature of natural objects. This is usually about 62 degrees Fahrenheit. For comparison we have tabulated the discharge of a Compressor having an intake capacity of 1000 cubic feet per minute, and have stated the volumes of the discharge in cubic feet at atmospheric pressure and at temperature of 62 degrees F.

Temperature of Intake Air.	Volume taken into Compressor.	Volume Discharged at 62 degrees and Normal Pressure.
0	1000 cubic feet.	1135 cubic feet.
32	1000 "	1060 "
62	1000 "	1000 "
75	1000 "	975 "
80	1000 "	966 "
90	1000 "	949 "
95	1000 "	940 "
100	1000 "	932 "
110	1000 "	916 "

The above tabulated Gains and Losses are due to changes in temperature only, and have no bearing whatever upon the power needed to work the Compressor. The temperature of the intake air does not change the power needed to operate the machine. The resulting efficiency is changed as above shown. Nature expands or contracts the product. The temperature of the earth increases as we descend. Ordinarily the increase is 1° for every 40 to every 60 feet. In the Comstock Mines the increase is about 1° for every 25 feet. Here water temperatures of 165° are found.

The Connections can be made at a merely nominal expense. The air conduit is of wood. It passes beneath the floor and communicates with the air ports by removable hoods. This method of taking air will, in summer, generally result in a gain of three to five per cent., even when the cold water spray is not used. The gain amounts to one per cent. for every five degrees that the air is taken in lower than the temperature of the engine room. In the winter forty to fifty degrees would be a very ordinary difference and proportionate gain result from the outside connection. The inlet conduit should have an area of at least fifty per cent. the area of the air piston, and should be made of wood, brick or other non-conductor of heat.

For Inlet Valves the ordinary poppet valves are open to much objection. Such valves are closed by springs, and to insure prompt closing at all speeds, especially when the valve stems become foul with dust and gummy oil, the springs must have quite a little strength. Springs exerting a force less than eight ounces per square inch of valve surface are too weak. The slight throttling of the inlet by these springs will scarcely be seen on indicator cards of the usual scale taken in the ordinary way. Notwithstanding the difficulty of detection the loss amounts to 3.41 per cent. in capacity, at the sea level; at higher altitudes it is greater. The partial vacuum, being a drag on the machine, consumes 1¼ per cent. more power for each revolution when the discharge pressure is 60 lbs. per square inch. Owing to the extra number of revolutions needed to make up for the loss of capacity it requires 4.8 per cent. more power to produce the same result than would be required with a free and full supply of air. By far the greater number of machines with poppet inlet valves do not have even as free a supply as that assumed above and the losses are still greater. With poppet valves another loss is known to exist, which is quite difficult to detect. These valves have large surfaces which are heated by the air under compression. The air as it is drawn into the compressor passes in *very thin streams* over these *heated surfaces* and is of necessity heated and rarefied in consequence. The losses due to hot inlet air have been explained and tabulated on the previous page. In the Norwalk Compressor these losses are all avoided.

The air is admitted to the cylinder by valves of the well-known Corliss Steam Engine Pattern, which have a positive movement from the main shaft. The port is large, is clear of obstructions, and opens directly into the cylinder.

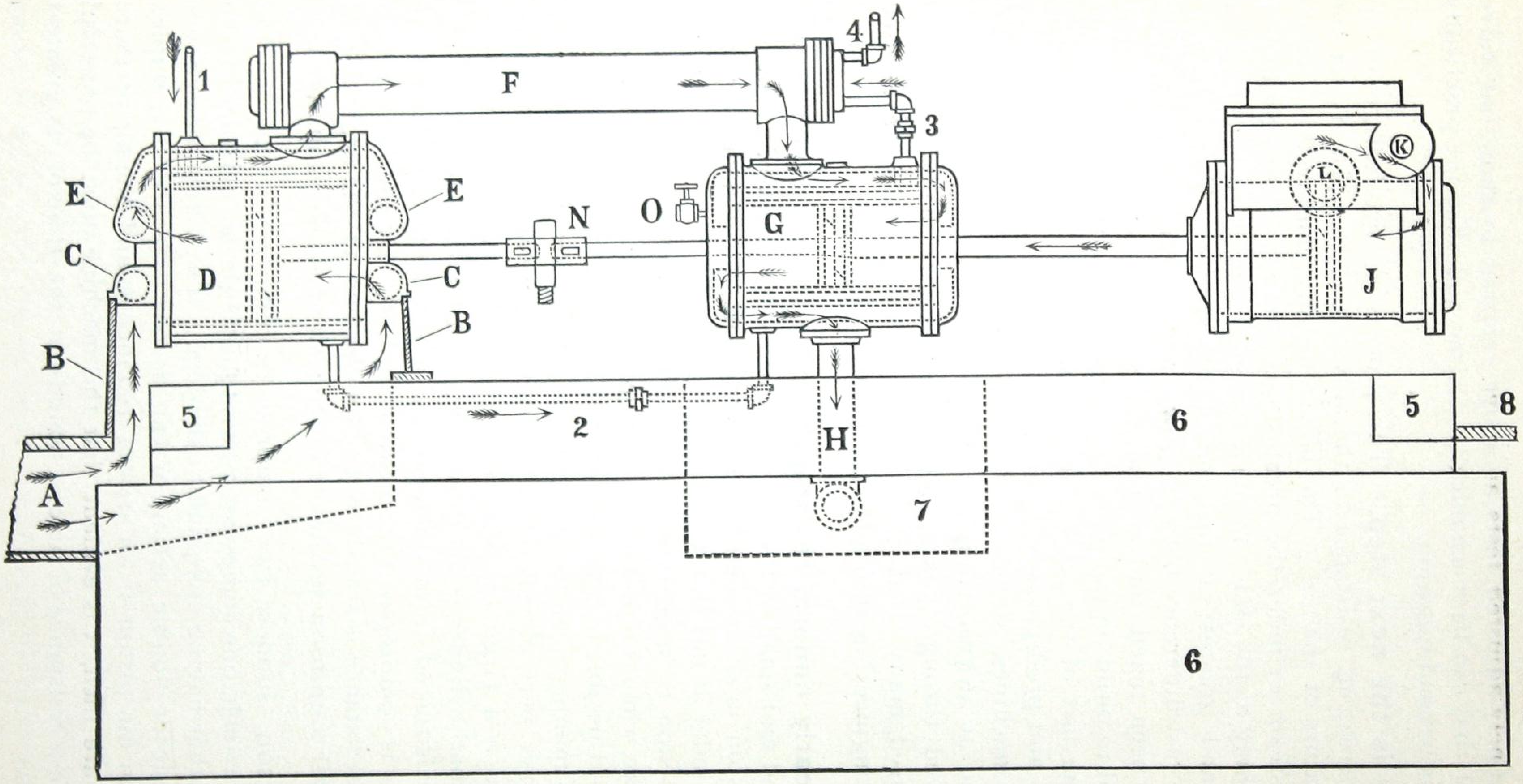
We have taken indicator diagrams from our compressors when running at 250 revolutions, also at piston speeds up to 500 feet per minute. With ordinary indicator springs no vacuum is discernable, but with an extremely light spring of only four pounds to the inch we can detect the slightest indication of a difference of pressure within and without the cylinder. Such a result must be expected even if the entire cylinder head had been removed, as air will not enter the cylinder without something to induce its movement.

But extreme and finely adjusted tests as above referred to show our valve movement to be all that can be mechanically desired and that the practically full supply of air is beyond question.

Compression is the next step. This process has two features of interest, viz.—the increasing resistance to the advance of the piston and the increasing temperature of the air. The power usually employed is a steam engine. In the steam cylinder the greatest pressure is at the beginning of the stroke and nothing at the end. In the air cylinder the pressure is nothing at the beginning and greatest at the end of the stroke. To equalize in some measure this vast difference between power and resistance, the ingenuity of mechanics has been taxed, and a great variety of devices has been employed. It is usual to build on the pattern of presses which do their work in a few inches of the last of the stroke, and employ heavy fly wheels, extra strong connections and prodigious bed plates. Counterpoise weights are also attached to such machines, steam is allowed to follow full stroke, steam cylinders are placed at awkward angles to the air compressing cylinders, and the motion conveyed through yokes, toggles, levers, and many joints, and other devices are used, many of which are entire failures, while some are used with questionable engineering skill and very poor results.

To obtain nearly uniform resistance the air cylinder should be conical, large at one end and small at the other. Of necessity this would be single acting, and the piston must be capable of expanding and contracting to fill the bore of the cylinder at any point. In such a cylinder at the first of the stroke, when the piston is large, it would encounter a light pressure, but at the last of the stroke, when the pressure is very great, the piston would be small and the engine would be able to overcome the resistance with ease. A machine constructed in this manner is, in the present state of the art, an impossibility. Its result is however very closely imitated in the Norwalk Compound Air Compressor, in which a large cylinder is employed to make the initial air pressure, while a small cylinder is used to effect the final and heaviest compression. The air is forced from the larger cylinder into the smaller, and in the smaller cylinder is compressed to the extent desired. By such an arrangement much of the resistance is transferred from the end to the beginning of the stroke and nearer a uniform resistance for the whole stroke is obtained.

For comparison, suppose two compressors compress air to 100 lbs. pressure per square inch, one compressor having a single air cylinder of the usual pattern, the other having compound cylinders. The single air cylinder can be either single or double acting or can be one attached to a duplex machine. With an air piston of an area of 100 inches, and the air pressure at 100 lbs. per square inch, it is evident that the machine must be powerful enough to overcome a resistance of 10,000 pounds at the time of its greatest effort.



Arrows on the water pipes show the direction of water circulation. When pistons move as indicated by the arrow on the piston rod, steam and air circulate in direction shown by arrows in the cylinders.

A—Inlet Conduit for Cold Air
B—Removable Hoods of Wood
C—Inlet Valve
D—Intake Cylinder
E—Discharge Valve
F—Intercooler
G—Compressing Cylinder

H—Discharge Air Pipe
J—Steam Cylinder
K—Steam Pipe
L—Exhaust Steam Pipe
N—Swivel Connection for Crosshead
O— Air Relief Valve, to effect easy starting after stopping with all pressure on the pipes.

1—Cold Water Pipe to Cooling Jacket
2 & 3—Water Pipe
4—Water overflow or Discharge
5—Stone on End of Foundation
6—Foundation
7—Space to get at Underside of Cylinder
8—Floor Line

The Compound Compressor is shown in outline by the cut, page 28. The large air cylinder on the left determines the capacity of the Compressor, and for our illustrations we have taken its piston at 100 square inches area. The small air cylinder in the center can have an area of 33⅓ square inches. The small piston only encounters the heaviest pressure, and at 100 lbs. pressure the resistance to its advance is 3,333 lbs. The resistance against the large piston is its area multiplied by the pressure which is caused by forcing the air from the large cylinder into the smaller cylinder, which is in this case 30 lbs. per square inch. But as this 30 lbs. pressure acts on the back of the small piston and hence assists the machine, the net resistance of forcing the air from the large into the small cylinder is equal to the difference of the area of the two pistons multiplied by the 30 lbs. pressure. This is 66⅔ by 30 and equals 1,999 lbs. Hence 1,999 lbs. the resistance to forcing the air from the large into the smaller cylinder plus 3,333 lbs. the resistance in the smaller cylinder to compressing it to 100 pounds is the sum of all the resistances in the compound cylinders at the time of greatest effort. This is 5,333 lbs. The time of greatest effort is at the end of the stroke, or when the engine is passing the center. In the single machine we have seen this resistance to be 10,000 lbs., hence we see that in the compound machine the maximum strains are less by over 46 per cent. or nearly one-half. By thus reducing the work to be done at the end of the stroke, more work is done in the first part of the stroke, and the resistance is made nearly uniform for the whole stroke.

The Next Step is to render the application of power also uniform for the whole stroke. This is accomplished in a very simple and effective manner. The steam and air pistons and crosshead are mounted on the same piston rod. These parts are purposely given weight enough so that it requires most of the power of the steam over and above the air resistance at the beginning of the stroke to start them forward at the required speed. At the end of the stroke, when the steam has become weak by expansion, the power stored up in the momentum of these reciprocating parts is given out in useful work, and the parts are brought to a state of rest by expending their force upon the air in the compressing cylinders. As the energy which can thus be stored and given out by the reciprocating parts depends upon their weight and the *square* of the number of revolutions, it is evident that rotative speed is the most important factor. Hence very long strokes are not desirable, because at the same piston speed the machines make fewer revolutions than machines of shorter strokes. Therefore, the power is not applied to the work so uniformly, and greater strains are brought on shafts, connecting rods and other parts, and larger fly-wheels, and frequently double engines are necessary for successful operation, especially when steam is to be used expansively The value of rotative speed for economical steam consumption is too well known to need reviewing here.

It is of interest, however, to note that the quick rotation that is valuable for applying the power uniformly also contributes to steam economy.

Uniform Resistance and Uniform Power both applied, as in the Norwalk Compressor, as direct end thrust and pull upon a straight steel piston rod, do not leave much work for fly-wheels to perform. Their presence, however, is necessary to regulate the steam valve motions, to control the length of stroke, to even up and balance trifling inequalities of power and resistance and to secure a uniform speed to the machine.

The Heat of Compression is the next feature of interest in the process. As air is compressed it rises rapidly in temperature. The temperature to which it finally attains depends upon the initial temperature and also upon the degree of compression, or in other words, the amount of work expended on it. The extent of this heating is shown in the following table; the air compressed being dry:

Temperature of air before compression,		60°	90°
Temperature of air compressed to	15 lbs.	177°	212°
" " "	30 lbs.	255°	294°
" " "	45 lbs.	317°	362°
" " "	60 lbs.	369°	417°
" " "	75 lbs.	416°	465°
" " "	90 lbs.	455°	507°
" " "	105 lbs.	490°	545°
" " "	120 lbs.	524°	580°

The heat of air when compressed is an illustration of the general law of the conversion of mechanical power into heat.

Other illustrations of this law of thermodynamics are very familiar to observers, the most common being the heat arising from friction, and the heating of any metal by successive blows of a hammer. The converse of the law holds good, for as air when compressed grows hot, so does air, steam or any gas grow cold when it expands in doing work. Many are familiar with the school-room experiment. A glass tube closed at one end has a piston carefully fitted to it. A bit of cotton wetted with bi-sulphite of carbon is attached to the piston. If now the piston is quickly forced down the barrel it will compress the air beneath it, and the heat thus developed will fire the cotton. If again the piston be forced down the barrel very slowly, and the air be compressed to the same extent, there will then be no flash of fire as before. The reason is obvious. For although heat is developed as in the first instance, yet by reason of the slow motion there is time enough for it to escape by conduction and radiation, and the temperature of the air does not rise to so high a degree. If now the barrel be surrounded by cold water the speed

could be greatly increased before a perceptible amount of heat could be accumulated. Still again, if the piston be forced half-way and then stopped and the air be allowed to cool and then the piston be forced the rest of its stroke, the actual movements of the piston could be made with great rapadity without accumulating an excessive amount of heat. In effect this is the plan adopted in the Compound Compressor.

The air is partially compressed in one cylinder, it then passes through an Intercooler where it is thoroughly cooled, and finally is compressed to the desired degree in the second cylinder. Both cylinders are surrounded by water jackets, and the Intercooler is a large chamber filled with small brass pipes through which cold water circulates.

No water is allowed in the cylinders in contact with the air, and all cooling is effected by surface coolers. Air is a poor conductor of heat, and in order to cool it thoroughly, it is necessary not only that every particle be in turn brought in contact with the cooling surface, but that it also have sufficient time to part with its heat. Much cooling cannot be expected of simple cylinder jackets, because the air in the cylinder is in a large body, it has very little time to give up its heat between the successive strokes of the piston, and also the advancing piston rapidly covers up the jacket and thus reduces its effective area. On the Compound Compressor there are two cylinder jackets which should be credited with all the useful effect due to such an attachment on any compressor.

In the Intercooler are found all the elements of successful cooling, for here the air is divided into thin streams, it comes in contact with large surfaces, and is given ample time to cool.

The value of Cooling Attachments is that they effect a direct saving of the power required for compression, and by keeping the parts cool make it possible to attain thorough lubrication. *Air compressed to five atmospheres or 60 lbs. pressure on the ordinary gauge, in a compressor without cooling arrangements, would be raised in temperature from 62 degrees to 373 degrees Fahr. Assume that the amount of air is such that it requires an engine of 100 horse-power to do the work. If now a *perfect cooling* apparatus is added to the compressor, the power required would be reduced from 100 down to $78\frac{4}{10}$ horse power. Or in other words the value of a perfect cooling apparatus to that compressor would be $21\frac{6}{10}$ horse power. So much cooling cannot be obtained from a single cylinder jacket for the reasons already cited.

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*On page 30 it is seen that in a compressor doing all the work in a single air cylinder and compressing to 75 or 90 lbs. pressure it is quite possible to have 400 to 500 degrees of heat. This is heat enough to char or decompose animal and vegetable matters in oil so that it becomes gummy and renders the parts foul with dirt instead of effecting the desired lubrication. We have several times had our attention called by letter to explosions of the air cylinders of *single cylinder* compressors. These explosions were powerful enough to wreck the machine and fill the engine room with flame. The only apparent cause was that mineral oil was used as a lubricant and the cylinder became hot enough to cause it to flash. In the Compound Compressor such accidents are impossible as no high temperatures are anywhere encountered.

In the Compound Compressor doing the same work the temperature of the air on leaving the first cylinder would be 199 degrees, if the cylinder had no jacket. All this heat above the atmospheric temperature can be taken out in the Intercooler. By thus cooling the air the original 100 horse-power required will be reduced to 88, 1-10th horse power. We have seen that by perfect cooling a further gain of 9, 7-10th horse power is possible. For this we put a water-jacket on each of the two air cylinders, and look to each water-jacket to return a useful effect of 4, 85-100 horse power, which is very reasonable compared with 21, 6-10 horse power, the amount required from the jacket of a single cylinder compressor.

We therefore conclude that in a 100 horse-power compressor when compressed to 60 lbs. it is possible to gain 21, 6-10 horse power by perfect cooling.

In a Single Cylinder Compressor all this cooling must be had in one cylinder, and the prospect of disappointment is certain.

In the Compound Compressor 11, 9-10th horse power is gained in the intermediate reservoir where perfect cooling is made absolutely sure.

The amount of cooling required from each of the two compound air cylinder jackets being only 4, 85-100 horse-power, its practical accomplishment can be relied on with confidence.

By reference to the table of temperatures given on page 30 it will be observed that the increment of heat is greatest during the early stages of compression. From the atmospheric pressure to 15 lbs. the temperature is raised from 60^0 to 177^0, the addition being 117^0.—But from 75 lbs. to 90 lbs. the increment of heat is only 39^0. This shows conclusively that the point of compression at which the cooling process should be most active is during the *early stages*. Hence follows the great value of the Intercooler before the air enters the second cylinder.

We have had our attention called to indicator diagrams published by some of our competitors, and taken from machines of their rivals and also from those of their own manufacture. One of these parties shows a compression line very near the isothermal line and publishes it with pardonable pride. The fact is overlooked that a leaky piston will reduce the compression line fully or even more effectually than any cooling of the air can do. In this particular case evidence of the leaky piston is given by the card in a most unmistakable manner. The intake pressure instead of being down to the atmosphere or below it, is above atmospheric pressure for the entire stroke and the pressure rises rapidly even before the piston has begun to advance on the return stroke. It may be here noted that the card will not always thus "give the whole thing away," and poor workmanship will then actually assist unchallenged in preparing apparent evidence of merit in a machine of the lowest grade.

Another of these publishers of "cards" reviews the subject with apparent great exactness, even carrying the results as far as the one hundredth part of one per cent. This care about figures becomes ludricous in the extreme when any engineer with skill enough to read an indicator diagram can without figuring, detect an error of over twenty per cent. in this mathematician's (?) interpretation of a competitor's card.

A knowledge of the subject and fairnes in representation is in our opinion requisite to gain and hold the confidence of American mechanics.

The advantages of Surface Cooling as above shown in comparison with the use of water in the air cylinder are several. The first consideration is that the product of compressors with surface cooling is dry air. This is a matter of much importance. When the air is heated by compression, if it is brought in contact with water it becomes saturated with moisture. Air when exhausted after doing work has a temperature far below zero. So low a temperature quickly freezes up all moisture in the air and deposits it as ice in the exhaust passages of the air engine, and in a short time they are choked up or entirely closed. This stops the machine and all work is suspended until it is thawed out. Frequently the moisture of saturated air freezes during the winter season in the main air pipe between the engine room and the mine, and becomes a subject of much annoyance. The remedy for these evils is simply to keep the air dry, by keeping water from it.

Water in air cylinders is also open to the further objection that it reduces the air compressor to the condition of a water pump, both as regards the great wear of parts and the limitation of speed. The cylinder, piston and valves must take all the chances against rust and the grit invariably present with water. In many localities, water, which would be quite suitable to run through jackets, would be very destructive to the finished surfaces of working parts if introduced into the cylinder. Water introduced into the cylinder takes the place of just so much air and reduces the capacity of the compressor. Power is required to force the water out of the air cylinder into the air discharge pipe. For the power thus expended there is no useful return As the water is increased in quantity to effect greater cooling, the power to force that greater quantity of water into the air reservoir is also increased. The quantity of water can be made so great as to require more power to force it into the reservoir than is saved by its cooling effect. It is therefore evident that there is a point below which it does not pay to cool with water in the cylinder. In practice this limit is reached when the air is still quite hot, showing thorough cooling cannot be economically obtained in this manner. Careful attention is required by the attendant that the supply of water be regulated so as not to flood the air cylinder when the machine is standing still or running slow, and also the water drip cock in the bottom of the air reservoir must be carefully watched to prevent flooding the air pipes or drawing off the water faster than the supply and thereby causing a serious blow off of compressed air. At the best, with a large collecting reservoir the water is

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A writer of experience says of this matter: "In view of the results attained it is '*simply folly*' to claim efficiency for the injection system. The claims are not true." Theoretical writers, and inexperienced builders advocate and practice injection. Most of the old adherents of the system have either changed their designs or are practically out of the market. The general plan of cooling by injection is controlled by no patents. It can be applied at trifling cost to any compressor and we are always willing to apply the scheme to our compressors without charge whenever the special circumstances of any case warrant a reconsideration of our general views of the subject.

discharged thoroughly charged or impregnated with compressed air, like that drawn from soda water fountains.

Clearance Space in the air cylinders is the point next in the order of compression which affects the capacity of the compressor and must be considered by the constructor. The space which is of necessity left between the piston and the cylinder-head at the end of the stroke is filled with air under compression. When the piston returns on the backward stroke this air must expand down to atmospheric pressure before any air can be drawn into the cylinder from the atmosphere. The expanding air, by its pressure on the piston, returns the power expended in compressing it, but by preventing the entrance of air from the outside, it causes a loss in the capacity of the machine. Builders of compressors employ three methods of reducing this loss; first by making very long strokes of piston so that the clearance becomes a smaller percentage of the cylinder's contents: second by filling the space with water; third by not allowing the full reservoir pressure to accumulate in the clearance space above the inlet valves. The first plan is attended with unnecessary expense in the first cost of machine and requires large foundations and much room in engine house. The second plan is entirely inefficient at any but the slowest speeds, inasmuch as the water or other fluid becomes churned to a foam and so thoroughly charged with air under compression that it does not perform the office intended. The evil effects of water in the cylinder have been described elsewhere. The third plan is adopted in the Compound Compressor. The clearance in the Intake Cylinder is filled with air of the light pressure only, which is required to force it into the smaller or the compression cylinder. The loss of capacity is thus made the least possible. A single compressor must have a stroke of 68 inches in order that its clearance loss should not exceed that of a compound compressor of 24 inches stroke, when both compressors are forcing against 60 lbs. pressure. With higher pressures the single compressor must have still longer strokes. At 75 lbs. it must be 96 inches. Such extreme long strokes are unadvisable, particularly when we see that all their advantages, together with many other desirable features, can be obtained by compound cylinders. We have obtained 5000 lbs. pressure in a Compound Compressor with a stroke of only 16 inches. If this had been attempted in a single cylinder Compressor, and the clearance had been equal to one 20th of an inch, no air would have been discharged, because all the air in the entire cylinder could have been crouded into the clearance space. Yet one 20th of an inch is less than most designers can plan and much less than most engineers dare run with at high speed. It is reasonably safe to say that the pressure could not have been satisfactorily obtained for commercial purposes except in a compound compressor. The reader must remember that *duplex compressors* are simply *two single compressors* attached to one shaft, and have none of the merits of compound compressors.

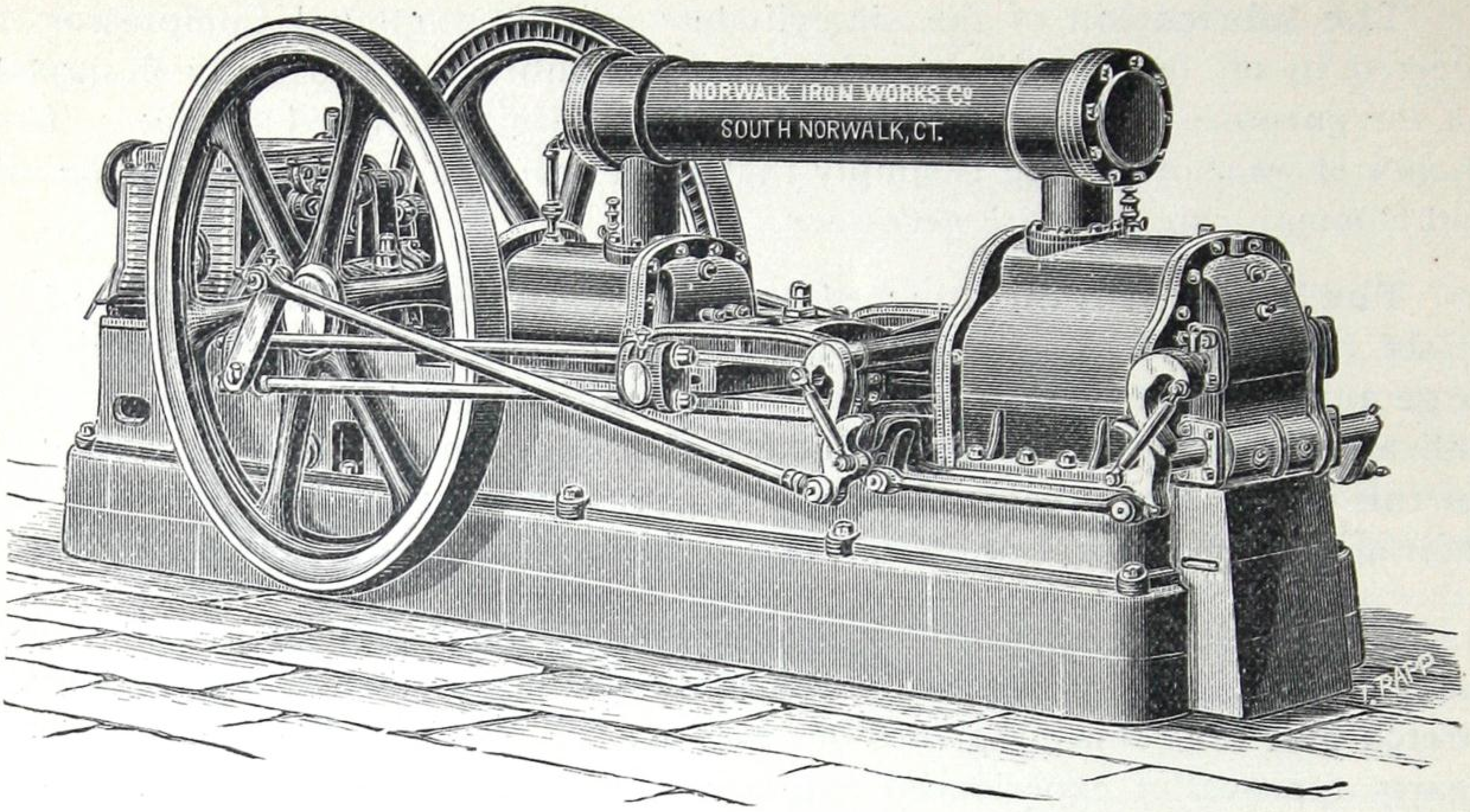
The lubrication of the air cylinders of the Compound Compressor is effected by oil, fed slowly drop by drop, by a lubricator especially designed for the purpose. The cylinders assume a beautifully polished surface. The chance of wear or cutting is simply that of an ordinary journal. Common oil and common care only are necessary.

The Steam Engine attached to our Standard Compressors is designed to attain the highest possible economy. The experience gained in building a large number of machines, and careful investigations with the steam engine indicator have resulted in the production of an engine particularly well adapted for this duty. The steam cut-off valves have a wide range and are quick in their action, giving a clear sharp point of cut-off and a perfect expansion line.

The cut-off is changed by turning a hand wheel at the back end of the valve chest. This wheel is easily accessible without requiring the attendant to stretch over the connecting rods or other moving parts. This fact meets the hearty approval of experienced engineers who appreciate the convenience of starting compressors slowly with throttled steam and full strokes and then when all is in readiness opening the throttle and running cut-off up short. The point of cut-off can be changed while the machine is in motion to meet any requirements of speed or pressure. Its position is shown by an index. Under ordinary circumstances with boiler pressures from 60 to 80 lbs. per square inch the admission of steam is cut off when the piston has passed through about one-fourth to one-fifth of its stroke. The exhaust steam can be run into a feed water heater or into the smoke-stack if desired to increase draft.

The economy of steam expansion is so obvious as not to require explanation even to those who are unskilled in steam engineering. The distribution of the work in the the air cylinders as explained before, together with their full supply and ample discharge ports, their extensive cooling arrangements, the uniform lubrication, the perfect balance of fly-wheels and reciprocating parts, allow a high rotative speed to be economically employed. Rotative speed as well as steam expansion is one of the factors of steam economy, and the capabilities of the combined compressor and engine in this respect must not be overlooked. It should also be noted that the capacity of the compressor increases in proportion to the speed and the advantage of a machine capable of high speed is self evident.

Two fly-wheels are used as shown by the cut, one on each side the machine. By means of a swivel in the centre of the cross-head the work is brought exactly equal upon both connecting rods. The "taking up" one rod shorter than the other cannot bring any strain on one greater than on the other. Under all circumstances of speed or adjustment the working effects are central and perfectly balanced.



List of Standard Air Compressors

DRIVEN BY STEAM.

In the following list, it will be observed that the LARGE AIR CYLINDER gives the CAPACITY of the machine For exact capacity, allowance must be made as stated on page 39. It will also be borne in mind that the SMALL PISTON ONLY encounters the pressure of the final compression, and hence a smaller steam cylinder or a higher rate of expansion can be used with the Compound Compressor than is possible with a compressor of equal power constructed in any other manner. This fact insures the highest economy in steam consumption.

Prices are quoted only to hold good for reasonably prompt acceptance.

EVERY MACHINE FULLY WARRANTED.

Diameter of Air Cylinder	Length of Stroke	Diameter of Compre'ing Cylinder	Diameter of Steam Cylinder	Revol'tions or Double Strokes per Minute	Capacity Cubic Feet Per Minute	Steam Pipe	Exha'st Pipe	Air Pipe	Water Pipe	Horse Power
8	10	5	8	200	116	2	2½	2	½	15
10	12	6¾	10	190	207	2½	3	2½	¾	28
14	16	9½	14	150	427	3	4	4	1	55
20	24	13½	20	110	960	5	6	5	1¼	125
26	30	17½	24	90	1659	6	8	6	1¼	215
32	36	21½	30	80	2686	7	10	8	1½	350

The Compressors in the list on page 36 are intended for producing compressed air at pressures required by the most advanced practice in driving machinery. They are provided with steam expansion valves which are adjustable, even while the machine is in motion, and range in their action from one-eighth to nearly the full stroke. High pressure steam with early cut off, or low pressure steam with late cut off, will do the same work.

Air pressures of sixty to one hundred pounds per square inch are produced by these machines with great economy. About one hundred and twenty-five pounds should be the ordinary limit, although in case of emergency they have repeatedly furnished air of two hundred pounds pressure. Usually, however, when such pressures are desired we should be informed and preparation be made accordingly. We publish elsewhere description of High Pressure machines designed for pressures up to 5,000 pounds.

The Speeds given in table are intended for the limit of continuous use. In many cases where other machines have given out, or from necessity otherwise arising, our compressors have been driven continuously during the emergency, night and day, at speeds twenty-five per cent. greater than the tabulated speed. It should be remembered that these compressors having mechanically moved values, and no water in the cylinders are thus not limited in speed by the usual requirements of the air cylinder but can be run the same as any first-class steam engine.

Sectional and Light Weight Compressors.

We make on order Compressors with their parts so divided as to be convenient for transportation on mule back or in wagons over difficult mountain passes. For use on board ship or in other situations where light weight and great efficiency are desired we build from special plans.

The Mountain, or High Altitude Compressor.

By reason of the height above the sea level there is such a difference in results obtained from compressors at different altitudes that we have found it expedient to manufacture a compressor especially calculated for mountain work. This we have termed for a trade mark distinction, "The Mountain, or High Altitude Compressor."

The Engines of these machines are the same as of our Standard Compressors. The Air Cylinders are proportionately larger. Where 60 to 100 pounds pressure is stated as the range of the Standard Compressors, under the same circumstances the range of the "Mountain Compressors" would be 45 to 60 in the smallest machine and 55 to 80 in the largest. With steam of equal pressure the air pressure can be economically carried to 100 pounds. As the machines are very efficient and desirable on work at sea level we give their capabilities at sea level as well as at various heights.

Diamt'r Air Cylin'r	Length of Stroke	Diam of Comp'g Cylin'r	Diam of Steam Cylin'r	Revl'ns per Minute	At Sea Level		At 2,000 feat		At 6,000 feet		At 10,000 feet	
					Capa'ty Cubic ft	Horse Power	Capa'ty	Horse Power	Capa'ty	Horse Power	Capa'ty	Horse Power
12	12	7	10	190	298	35	280	34	244	32	214	30
16	16	9½	14	150	558	70	524	68	462	64	405	60
20	20	13½	18	120	872	110	819	107	722	100	634	94
22	24	13½	20	110	1160	145	1090	140	960	132	843	124

It is seen from the above list that the delivery and power of the Compressors decrease as the height increases. As the capacity decreases in a greater ratio than the power necessary to compress, it follows that operations at a high altitude are more expensive than at sea level. At 10,000 feet this extra expense amounts to over 20 per cent. The importance of positively moved Corliss Inlet Valves becomes more and more evident as the altitude increases.

On inquiry reference will be given to machines now in operation.

Prices of machines of larger capacity, also of machines for compressing to extreme high pressures, furnished on application.

Machines for compressing and liquifying gases built to order.

For Compressors arranged for Water Power see list page 42.

Capacity to bore Cylinders 110 inches diameter, and to turn Fly Wheels of 24 feet.

Lake Superior above sea level,	602	feet.
Lake Superior Mines above sea level	1,000 to 2,000	"
Pueblo, Col., above sea level,	4,713	"
Trinidad, Col., " "	6,034	"
Colorado Springs, Col., above sea level,	6,048	"
Raton Tunnel, Col., above sea level,	7,688	feet
Silver Cliff, Col., above sea level,	7,990	"
Leadville, Col., " " "	10,150	"
Raton, New Mexico " "	6,688	"
Santa Fe, " " " "	7,013	"
Chihuahua,	4,633	"

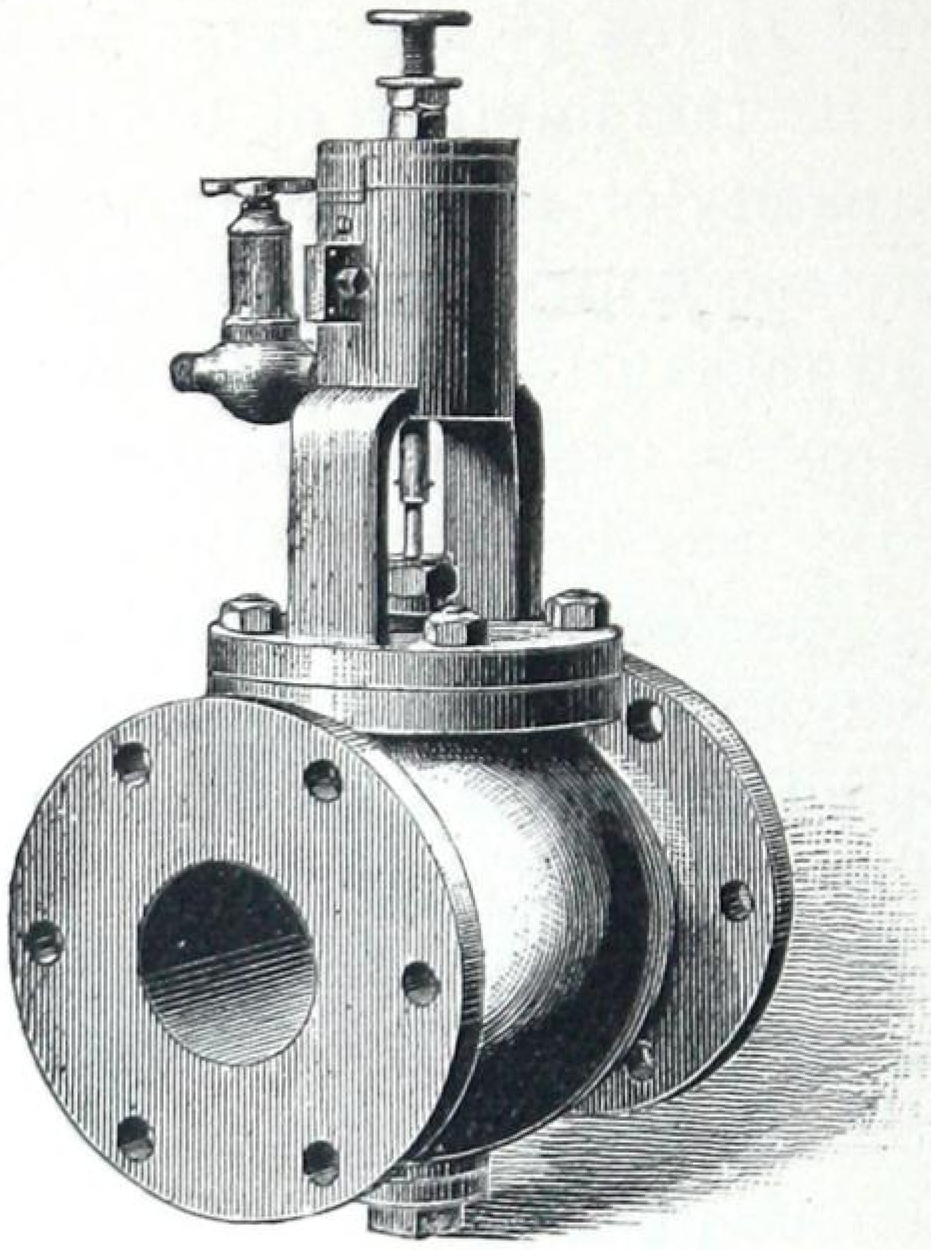
Capacity of Compressors.

It is a common practice to multiply the area of the air piston by the distance it travels in a minute, and to state such amount as the free air capacity of the Compressor. To ascertain the bulk of air in the compressed form, it is necessary to add 15 lbs. to the guage pressure, divide the amount by 15 and the result will be the number of atmospheres in the air of that pressure. The free air capacity of the Compressor divided by the number of atmospheres will give the amount of air after compression. This amount must be reduced by allowances of various kinds. The losses due to poor designing and workmanship, the use of warm induction air, insufficient supply, losses in clearance and leaks may be quite serious In some machines these losses amount to a clear 30 per eent. of their theoretical capacity, whereas ten per cent. should be liberal for all ordinary contingencies. We have shown how some losses are avoided and others reduced to the least possible in the Norwalk Compressor. There must, however, be an allowance made in the capacity of all Compressors by reason of their heights above the sea level. At an elevation the air is not so dense as at the sea level, and hence at each revolution the Compressor will take in a less weight of air and be able to do less work. To make exact comparisons of efficiency it is necessary to know whether the compressed air is used expansively or at full stroke, or whether the actual work done is to be compared. Generally speaking, the Compressor will run at less power at the elevation than at the lower level, but its capacity in the amount of compressed air produced will be so much less at the elevation that the net result is that more power is used to do the same work at a height than at the sea level.

As a very common practice is to use air in drills and like machines at full stroke, we append a table of efficiencies of Compressors when the air is so used at 60 lbs. per square inch gauge pressure, and at various heights above sea level.

Height in feet above sea level.	Barometer.	Efficiency of Compressor.
0	30 inches.	100 per cent.
500	29.42 "	98.4 "
1,000	28.85 "	96.9 "
1,500	28.34 "	95.5 "
2,000	27.78 "	94. "
3,000	26.74 "	91.1 "
4,000	25.70 "	88.1 "
5,000	24.73 "	85.9 "
6,000	23.83 "	82.8 "
7,000	22.93 "	80.2 "
8,000	22.04 "	77.5 "
9,000	21.22 "	75.1 "
10,000	20.43 "	72.7 "
12,000	18.92 "	68.0 "

PRESSURE REGULATOR
FOR
AIR COMPRESSORS.



This Regulator is intended to be placed in the steam pipe supplying steam to an air compressing engine. Its operation is to shut off the steam when the air pressure reaches the fixed limit and to admit more steam whenever the consumption of the compressed air causes the pressure to show a tendency to fall below the desired point. The results are that the speed of the air compressor is determined by the consumption of air and a uniform pressure is maintained in the air reservoir.

The valve shown above, having a large globe body, is a perfectly balanced valve. It can be moved up or down with very slight effort and is not affected by the pressure of the steam. This valve is placed in the steam pipe,—flanges being provided for the connections. An upward movement of the valve shuts off the steam and the downward movement opens the passage again.

Above the valve is a small cylinder, having a piston connected to the steam valve below by the stem plainly shown in the cut. At the side of the cylinder is a small spring safety valve. The under side of this safety valve is connected by a small pipe with the air reservoir. The small hand wheel on the top of the safety valve can be adjusted so that the valve will lift or "blow at any pressure desired.

THE

Norwalk Iron Works Co.

SOUTH NORWALK, CONN.

Dear Sir:

You will confer a favor by acknowledging the receipt of our Air Compressor Circular sent herewith. For this purpose a Postal Card is preferred for convenience and uniformity in filing.

Yours, very truly,

E. HILL, Treas.

When the pressure in the air reservoir reaches the fixed limit the safety valve will begin to allow air to pass it to escape. The air passes into the small cylinder beneath the piston and if no escape was provided would drive the piston to the top of the cylinder. To regulate this action a very fine slot is cut in the side of the small cylinder. When the piston rises it uncovers this slot and thus furnishes an escape for the air which is passing the safety valve. If only a little air passes the valve then a small part of the slot will accommodate it and the piston will take a low position. With more air escaping, the piston will rise higher and uncover more of the slot and thus provide a larger opening for its exit. As the slot is very fine a very little difference in the quantity of air will cause the piston to assume a low or a high position. In our latest constructions the slot is placed on the rod joining the valve stem, instead of on the side of cylinder as shown in cut. After the small safety valve begins to blow an almost insensible increase of pressure in the reservoir will furnish more air sufficient to carry the piston to the top of the small cylinder. Thus any degree of regulation is obtained by very little difference of pressure. As the air which works on the piston in the small cylinder has only the work of lifting the piston and valve sufficient to uncover enough of the slot so it can escape, its pressure is very slight,—not more than a person can blow with the mouth. The piston is fitted very loosely and the whole apparatus moves as nearly without friction as can be imagined.

When this regulator is applied to compressors having a single steam cylinder it is possible for the valve to be carried so high as to shut off all steam and stop the engine on the center. This would be objectionable. We therefore place on the top of the small cylinder a screw stop which can be set to prevent the closing of the steam valve more than is sufficient to run the engine at the slowest speed at which it will pass the centers.

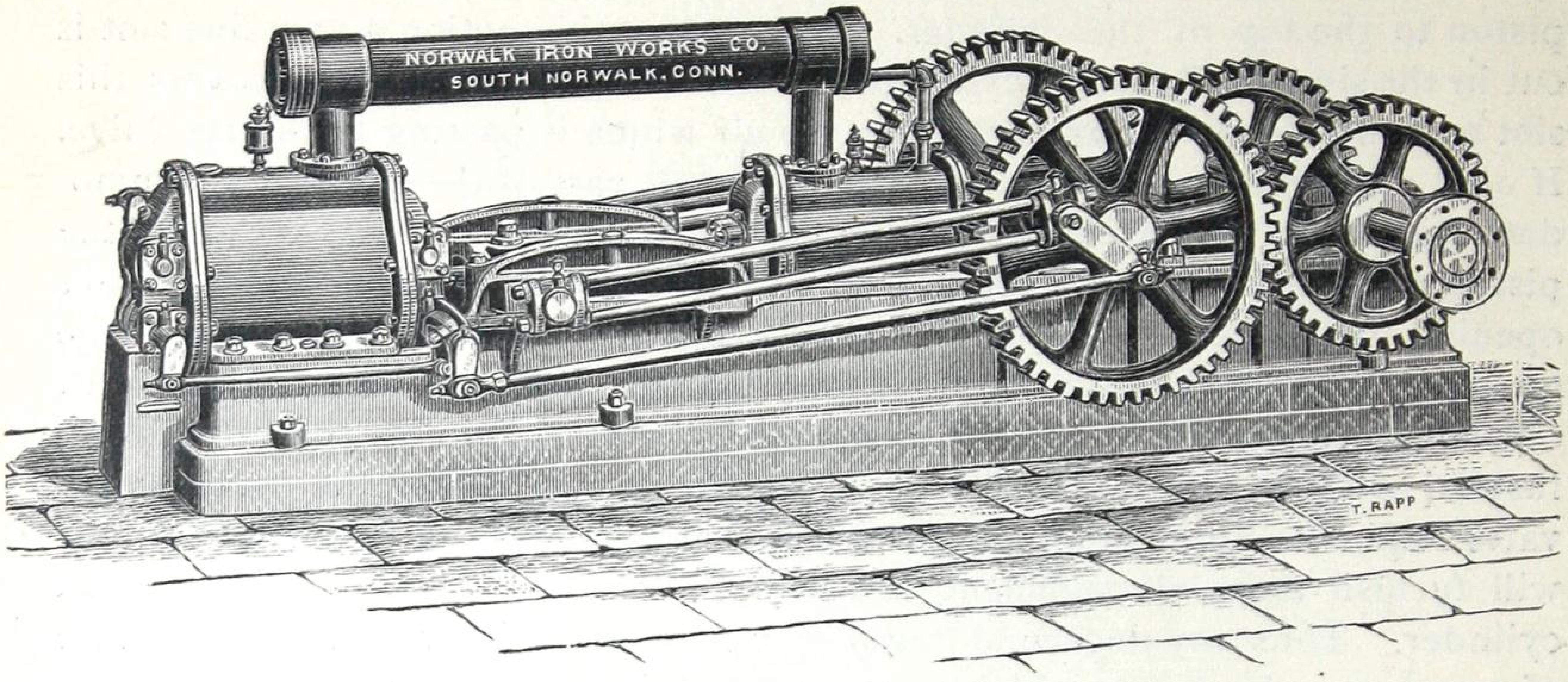
If no air is being used at such a time, the air which is compressed at this slow speed can find escape at the main safety valve on the air reservoir. This safety valve on the reservoir can be set to blow at about one or two pounds pressure more than the little safety valve which is attached to the Regulator. In practice the main safety valve will rarely blow.

The advantage of this Regulator over regulators operated by full direct pressure is that it moves with little friction and with slight difference of pressure. Regulators operated by direct pressure require their pistons to be tight and as they are loaded down with weights, the friction and inertia of the parts render such regulators of little use.

PRICE LIST.

Size of Steam Pipe	½	¾	1	1¼	1½	2	2½	3	4	5	6	7	8	10
Price............	$30.	32.	36.	40.	46.	60.	72.	90.	128.	220.	280.	340.	380.	420

COMPRESSORS TO BE DRIVEN BY WATER POWER OR FROM A LINE OF SHAFTING.



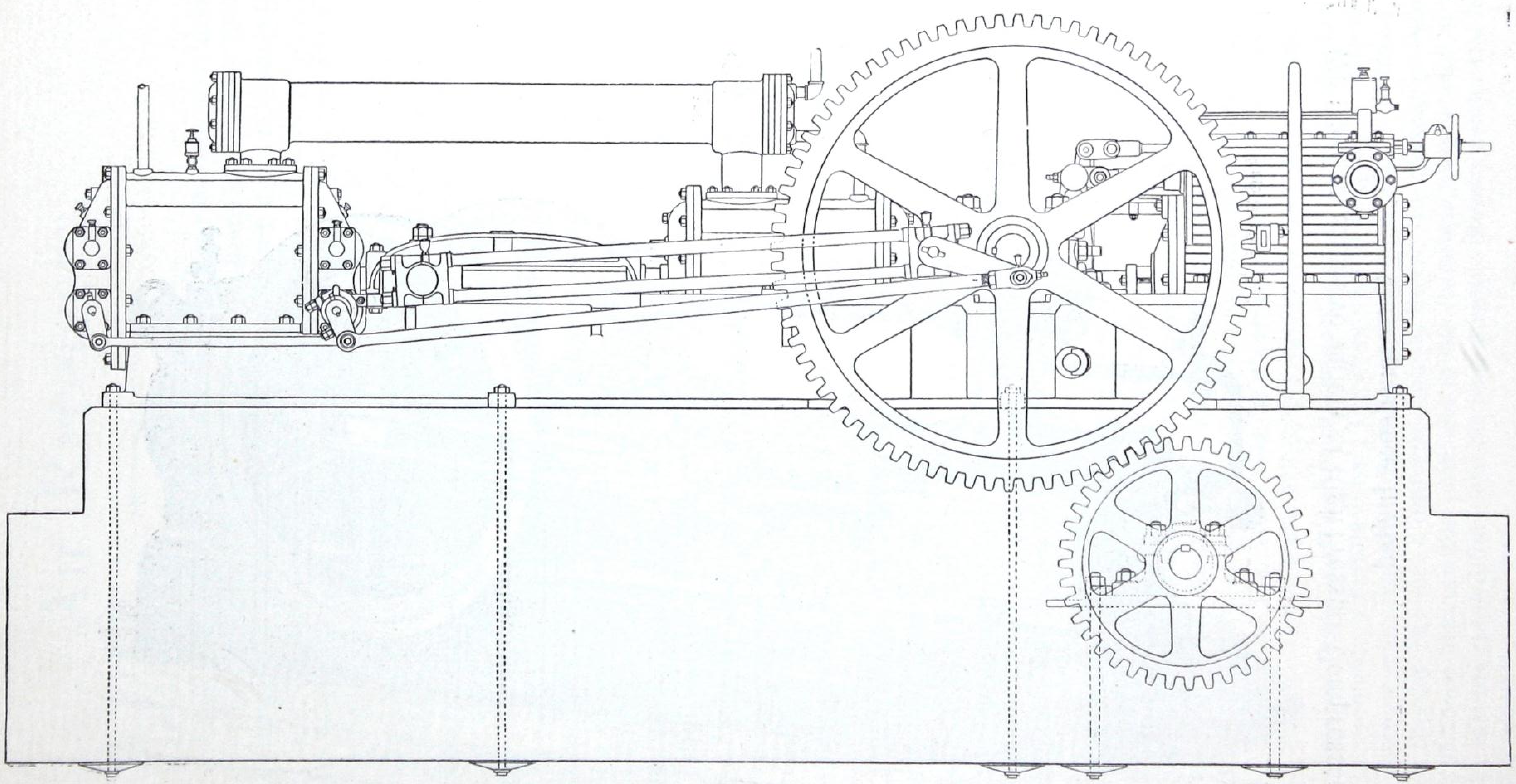
The above cut illustrates a 20" x 24" Compressor, designed to be driven by Water Power.

The Air Cylinders and connections are the same as those of steam driven compressors already described. In place of the steam cylinder, Cut Gears are placed with heavy shafts of fine hammered iron and pillow blocks having adjustable boxes of the latest improved pattern. The pinion shaft extends out from one side of the machine as shown, and is made of a length convenient for the position where the machine is to be placed and has a coupling for connecting to the driving shaft. The power is sometimes applied by a belt. In such a case the driving pulley is placed on the pinion shaft where the coupling is shown in the cut, and the shaft is further extended to rest in an out board pillow block.

The proportions of the gears are varied to suit the speed of the shafts from which power is taken.

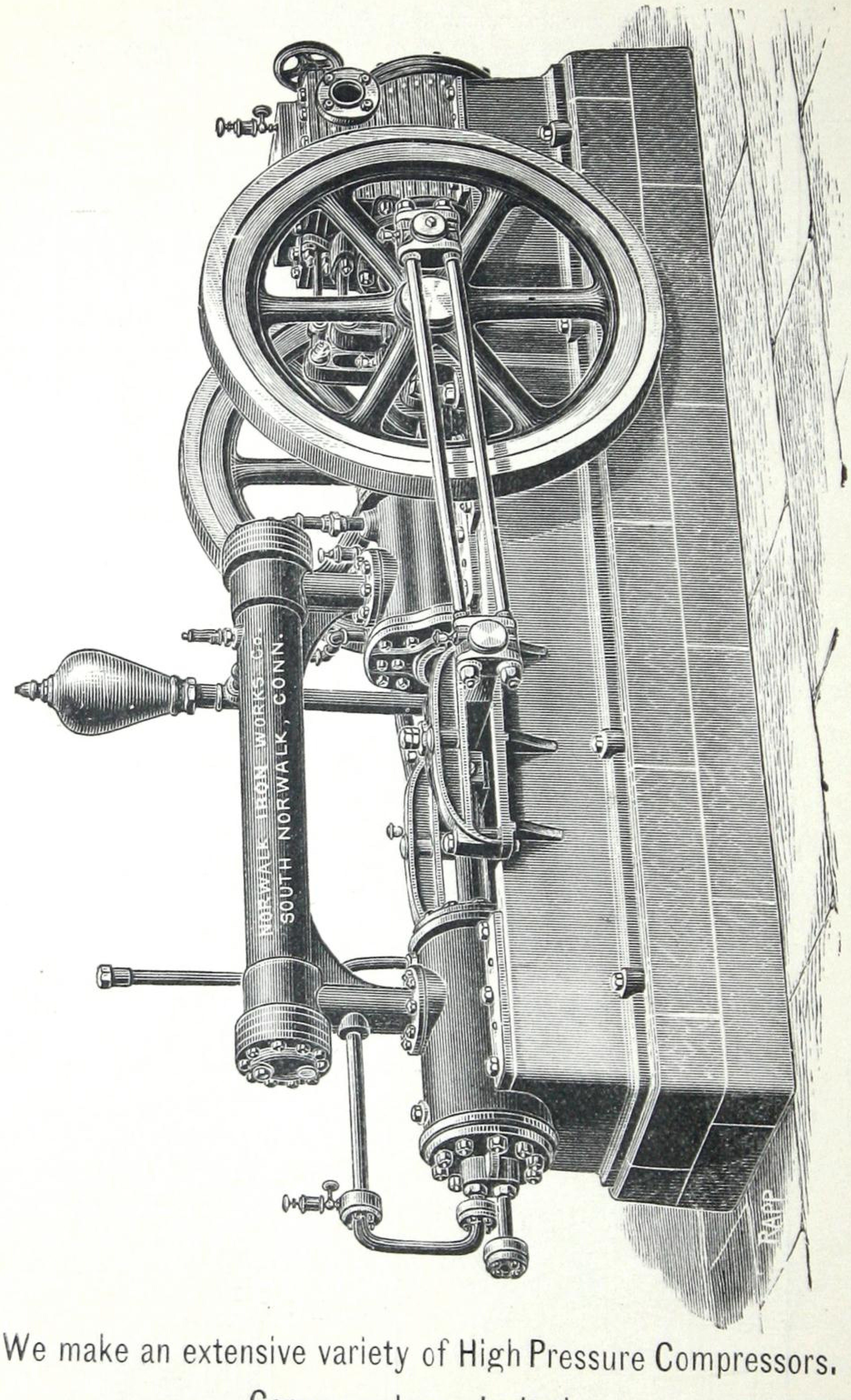
We manufacture this style of Compressors in the same sizes as the Standard Compressors given on page 36 and the High Altitude Compressors page 38 and can readily adapt any of our Special Compressors to be driven in this manner.

We also make a special Combination Compressor, illustrated on page 43, which can be driven by water power or by steam, or by both at the same time. This pattern is particularly desirable in localities where the water power is not sufficient for the entire year. The lists of these varieties of compressors would in all essential features be repetitions of the lists on pages 36 and 38. We have the machines either completed in stock or in such state of progress that prompt delivery can be assured. As this is a new pattern of compressor and offered only by ourselves we will invite correspondence from interested parties.



Combination Steam and Water Power Compressor.

Special Compressors for Very High Pressures.



2000 TO 5000 POUNDS PER SQUARE INCH.

We make an extensive variety of High Pressure Compressors.
Correspondence Invited.

Air Receivers.

The uses of compressed air are so varied that no definite rules can well be laid down to cover all requirements of the receiver. In fact, if we judge by what we find in compressing plants already erected, the subject seems to have been given very little attention. That a receiver is desirable seems to be generally conceded. But for what purpose, of what size, where placed and how connected, seem not to have been matters of careful thought or of definite agreement.

One of the first ideas which seem to enter the minds of most people in connection with the Receiver, is that it will act as a reservoir of power. This is true to some extent, providing the Receiver is made of sufficient size. But the size needed is so great as to be prohibitory of any such dependence. For example, a 20 inch compressor, when working at 60 lbs. pressure, would require a Receiver five feet in diameter and fifty feet long, in order that the Receiver could keep up the work of the compressor for only one minute after the compressor was stopped, and not have the pressure fall more than fifteen pounds. If the compressor was at work and demands were made on it for twenty-five per cent. more than its capacity, this large Reservoir, together with the compressor, would supply the demand for only four minutes. From that time the consumption must be less than the capacity of the compressor, in order that the pressure can be restored in the Reservoir.

This plan of operations can never be anything but unsatisfactory, and the money spent in Reservoir would be better put in the purchase of a compressor which is fully equal to the greatest demands upon it.

The second purpose of a Receiver is to compensate for the pulsating effect of each stroke of the compressor. As the air comes from the compressor into the pipe, unless there is sufficient space for its immediate accommodation, the pressure will run up momentarily far in excess of the average pressure in use.

This throws unnecessary strain on the compressor and consumes power. If the discharge pipe is quite large for a long distance, it will in a measure help the matter; but the more satisfactory arrangement is a Receiver of moderate capacity placed conveniently near to the compressor, and connected with it by a pipe of sufficient size. This will relieve the compressor at once, will equalize the pulsations of the discharge, and cause the air to flow with a uniform velocity in the pipe leading off to the work.

The third use of Receivers is to keep the friction of air in the pipe system as small as possible. To best accomplish this a Receiver is needed as near as possible to the point where the air is used. It has already been explained how a Receiver is useful near the compressor to prevent the rise of pressure above the average when the air is forced into the pipe. The converse of this must also be observed as well. When air is quickly withdrawn from the pipe the pressure will momentarily fall below the average.

A Reservoir as close to the workings as possible will largely prevent this loss of pressure and stop the momentary fluctuations. The Receivers by keeping a uniform pressure at each end of the pipe cause the air to flow through the pipe with a uniform velocity. The pipe friction thereby becomes a uniform quantity due to the average consumption of air, and is the difference between the pressures in the Receivers at each end of the pipe. The Receivers by making these differences the least possible thereby render the friction of the pipe the least possible.

The fourth purpose of a Receiver is to drain out water from the air. This it accomplishes by allowing the air to pause in its flow, to cool and to drop the water which would otherwise be carried onward by the force of the current. This use of a Receiver is particularly required with compressors using water in the air cylinder, and with such compressors the Receiver must of necessity be much larger and more expensive than with dry air compressors. Much of its space is filled by the water, and the attention of the attendant is required that it may not become wholly filled with water and therefore become useless.

With compressors doing their work without water in the air cylinder, there is not the same necessity of a Receiver for draining the air. Yet, as even the natural atmosphere contains moisture, particularly during the warmer summer months, it is not infrequently the case, that at intervals of a few days a little moisture can be drawn from the Receivers of any air compressor. It is desirable that whatever moisture there may be should be stopped at the Receiver. The style of Receivers most commonly in use are open to the objection that having the inlet and outlet pipe directed toward or running parallel to the centre line of the Receiver, the air soon forms a direct current from inlet to outlet. This action greatly impairs the cooling and draining effect of the Receiver.

In order to use the entire surface of the Receiver for cooling, and to insure that each particle of air remains in the Receiver the longest time possible, we make a novel disposition of inlet and outlet pipes. The Receiver is of the usual cylindrical form, and we prefer to place it on end although the horizontal position can be employed if for any sufficient reason.

When in the upright position the air inlet pipe is led in near the top, and in a direction tangential to the rounded surface of the cylinder. This gives the body of air in the Receiver a rotary motion. The outlet pipe leads from the lowest part of the Receiver that the air for use may be taken from the coolest part and hence be more dry. These features are the subject of Letters Patent. By the construction described, the air passes in a spiral motion through the Receiver, and each particle is exposed to the entire surface of the Receiver, and in consequence is cooled the utmost possible.

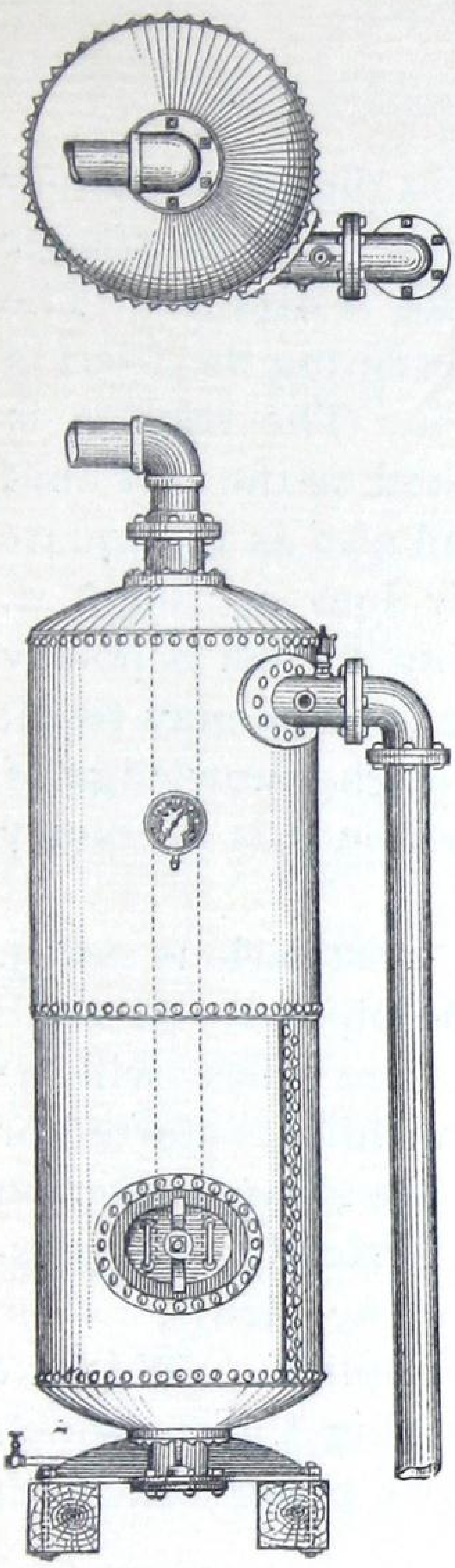
As the great majority of compressors are used for mining operations, we have prepared a list of standard sizes of Receivers for use with compressors when so employed. We have carefully determined the various sizes, so that all beneficial effects may be obtained without making the Receiver unnecessarily large and costly.

The Receivers of this list are intended for working pressures up to 100 pounds per square inch.

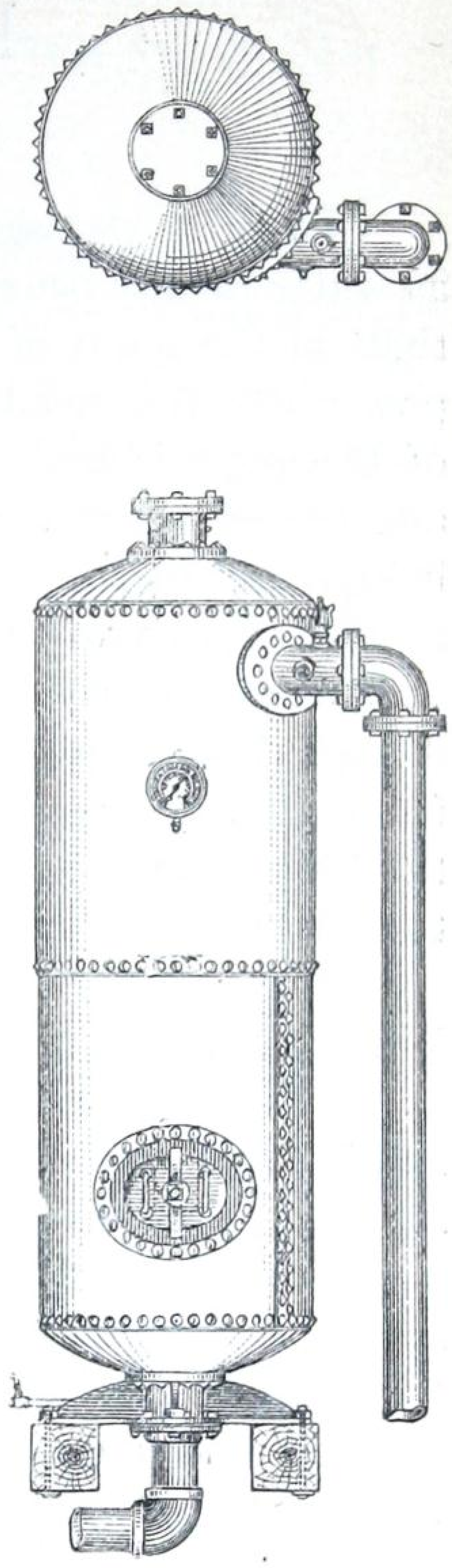
They are furnished complete with Safety Valve, Pressure Gauge, Blow Through Cock and Flanges, for connecting Inlet and Dicharge Pipes.

Diameter.	Length.	Size of Pipe.
24 inches.	4 feet.	2½ inches.
30 inches.	5 feet.	4 inches.
36 inches.	8 feet.	5 inches.
36 inches.	13 feet.	6 inches.
42 inches.	16 feet.	8 inches.

The connections are made by flanges, which is the only proper and mechanical method for such situations. The movement of a long line of pipe by heat and cold will soon loosen pipes screwed directly into the boiler iron shell. The flanges have a more substantial hold and are not so affected. The Receivers have a man-hole, which is so situated with respect to the connections as to be accessible when the Receiver is in the upright or horizontal position.



No. 1



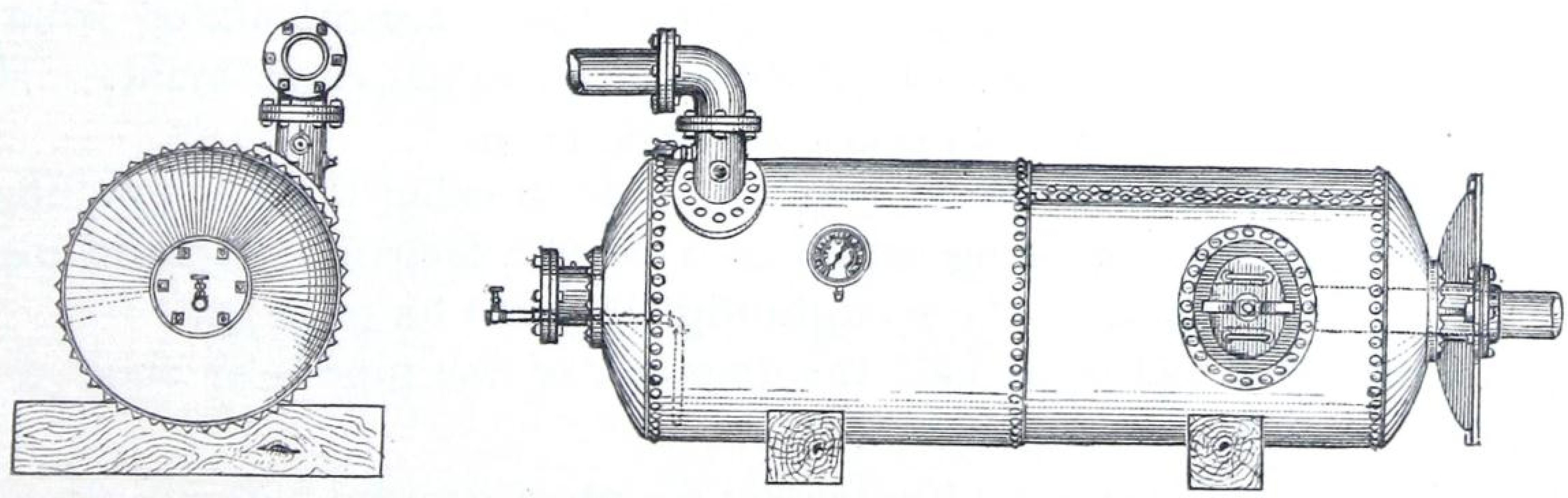
No. 2

The cut shows our Standard Air Receiver and illustrate how readily it can be adapted to any situation.

Cuts Nos. 1 and 2 show the positions most desired and usually adopted for the engine room or outside the mine.

The air is run in near the top in both cases. In No. 1 the main air pipe leads off from the top, a section of pipe is shown by the dotted lines taking the air from near the bottom of Receiver. No. 2 shows the main air pipe leading from the bottom of Receiver, and passing out beneath engine room floor.

No. 3 shows the Receiver on its side, as in a gallery of a mine. The air pipe is shown leading into its



No. 3

upper side, as would be the case when the main air pipe is carried along the roof of a mine. If the main air pipe was laid on the ground, it is evident that by rolling the Receiver over, its nozzle would come in a position equally convenient for the connection. The air can be led from the Receiver in either or both directions.

Friction of Air in Pipes.

Air in its passage through pipes is subject to friction in the same manner as water or any other fluid. The pressure at the Compressor must be greater than at the point of consumption in order to overcome this resistance. The power which is needed to produce the extra pressure representing the friction of the pipe, is lost, as there can be no useful return for it. The friction is affected by very many circumstances, but chiefly to be noted, is the fact that it increases in direct proportion to the length of the pipe and also as the square of the velocity of the flow of air. The pressure of the air does not affect it.

The losses by friction may be quite serious if the piping system is poorly designed, and on the other hand extravagant expenditure in pipe may result from a timid overrating of the evils of friction. A thorough knowledge of the laws governing the whole matter, as well as a ripe experience, is necessary to secure true economy and mechanical success.

The loss of power in pipe friction is not always the most serious result. When a number of machines are in use in a mine and the pipes are so small as to cause a considerable loss of pressure by friction, then there will be sudden and violent fluctuations in pressure whenever a machine is started or stopped. Breakages will be of common occurrence as the changes are too quick to be entirely guarded against by the attendant. Perfectly even pressure at the compressor is no safeguard against this class of accidents. The trouble arises in the pipe and the remedy must be there applied. We have devised and patented a system of Reservoirs and Governing Valves which regulate these matters perfectly and allow of successful work being done with pipes which would otherwise be entirely inadmissable.

We give on pages following tables showing the losses by friction at different speeds in pipes of various sizes. These tables are calculated from the data of the Sardinian Commission, deduced from actual experiment. Many additions have been made from original calculations.

We give on this page below an original table showing the effect of elbows. The friction is given as being equal to a certain length of straight pipe of same size. The friction of the straight pipe is given on page 49.

An elbow with radius of half the diameter of the pipe is as short as can be made.

Radius of Elbow	5	diameters.	Equivalent	length	of	straight	pipe	7.85	diameters
"	3	"	"	"	"	"	"	8.24	"
"	2	"	"	"	"	"	"	9.03	"
"	1½	"	"	"	"	"	"	10.36	"
"	1¼	"	"	"	"	"	"	12.72	"
"	1	"	"	"	"	"	"	17.51	"
"	¾	"	"	"	"	"	"	35.09	"
"	½	"	"	"	"	"	"	121.20	"

LOSS OF PRESSURE IN POUNDS PER SQUARE INCH, BY FLOW OF AIR IN PIPES.

Calculated for Pipes 1000 Feet Long.

FOR OTHER LENGTHS THE LOSS VARIES DIRECTLY AS THE LENGTH.

Velocity of Air at the Entrance to the pipe.		ONE INCH PIPE.			TWO INCH PIPE			TWO AND ONE-HALF INCH PIPE.		
Meters per Second	Feet per Second	Loss of Pressure in Pounds	Cubic ft of Free Air passed per minute when compres'd to 60 lbs. above the atmospr	Cubic ft. of Free Air passed per minute when compres'd to 80 lbs. above the atmospr	Loss of Pressure in pounds	Cubic ft. of Free Air Com pressed to 60 pounds	Cubic feet of Free Air Compressed to 80 pounds	Loss of Pressure in pounds	Cubic ft. of Free Air Compressed to 60 pounds	Cubic feet of Free Air Compressed to 80 pounds
1	3.28	.1435	6.	7.	.0794	23.	29.	.0574	32.	41.
2	6.56	.6405	12.	15.	.3050	46.	59.	.2562	65.	82.
3	9.84	1.4545	18.	22.	.7216	69.	88	.5818	97.	124.
4	13.12	2.5620	24.	29.	1.2566	93.	117.	1.0248	130.	165.
5	16.40	3.9345	29.	37.	1.9642	116.	146.	1.5738	163.	207.
6	19.68	5.4225	35.	44.	2.7120	139.	175.	2.1690	195.	247.
8	26.24	10.2480	47.	59.	5.0264	185.	234.	4.0992	260.	330.
10	32.80	15.7380	59.	74.	7.8568	232.	294.	6.2952	326.	413.
		THREE INCHES.			FOUR INCHES.			FIVE INCHES.		
1	3.28	.0463	48.	60	0347	86.	109.	.0287	134.	169.
2	6.56	.2092	96.	121.	.1525	172.	217.	.1281	268.	239.
3	9.84	.4880	144.	182.	.3608	258.	326.	.2909	402.	509.
4	13.12	.8381	193.	243.	.6283	343.	436.	.5124	537.	678.
5	16.40	1.3176	241.	304	.9821	429.	544.	.7869	671.	844.
6	19.68	1.8080	289.	364.	1.3560	515.	653.	1.0845	805.	1017.
8	26.24	3.3525	386.	486.	2.5132	687.	871.	2.0496	1073.	1357.
10	32.80	5.2704	480.	607.	3.9284	859.	1088.	3.1476	1342.	1696.
		SIX INCHES.			EIGHT INCHES.			TEN INCHES.		
1	3.28	.0232	193.	244.	.0173	343.	434.	.0143	537.	680.
2	6.56	.1046	386.	488.	.0762	687.	864.	.0640	1073.	1359.
3	9.84	.2440	579.	633.	.1805	1030.	1303.	.1455	1610.	2039.
4	13.12	.4190	772.	977.	.3141	1373.	1736.	.2562	2146.	2719.
5	16.40	.6588	965.	1221.	.4910	1717.	2171.	.3934	2683.	3399.
6	19.68	.9040	1158.	1466.	.6780	2060.	2605.	.5423	3220.	4079.
8	26.24	1.6762	1544.	1954.	1.2556	2747.	3473.	1.0248	4293.	5438.
10	32.80	2.6352	1931.	2443.	1.9642	3434.	4342.	1.5738	5367.	6798.

The resistance is not varied by the pressure, only so far as changes in pressure varies the velocity. It increases about as the square of the velocity, and directly as the length.

Elbows, short turns and leaks in pipes all tend to reduce the pressure in addition to the losses given in the table.

TABLE FOR EQUALIZING PIPES.

We give below an original table for ascertaining the proper size of branch pipes. The size of main is given in the column at the left. The number of branches is given in the line on the top, and the proper size of branches is given in the body of the table on the line of each main and beneath the desired number of branches.

It is quite commonly believed that the relative carrying capacity of pipes is proportionate to their area. This is not so. Four 5 inch pipes have the same area as one 10 inch pipe, but they will not carry as much fluid without greater loss from friction for each foot of length. For every inch of length the surface of the 10 inch pipe measures 31.4 square inches; the surface of each 5 inch pipe is 15.7 square inches, and of the four pipes it is 62.8 square inches. The friction surface of the four pipes is thus double that of the single pipe, and the pipes must be increased in size to have a carrying capacity equal to the single pipe. In the table opposite the 10 inch main, and in the column for 4 branches, is given 5.74, the size for a branch to carry one-fourth as much as one 10 inch pipe. The nearest commercial size is six inches. If it is desired to take from a main a certain proportion of its capacity and then to continue with a main of smaller size, the proper sizes can be had from the table. For example, it is desired to carry away one-third the capacity of a 10 inch pipe. The table shows that one 10 inch equals three pipes 6.44 inches in diameter. Hence the branch will be $6\frac{1}{2}$ inch pipe. The continued main should have capacity of two pipes each 6.44 inches in diameter. Following down the 2 branch column of the table, we find that a 9 inch pipe equals two pipes, each 6.82 inches diameter, hence it is quite sufficient for the main beyond the branch.

In commercial sizes the nominal $1\frac{1}{4}$ inch pipe is generally over-size. Frequently it is as large as $1\frac{3}{8}$. It is safe to call it 1.3 and we have so figured it in the table. We have given exact sizes for branch pipes. The designer of the pipe system can thus better select the commercial sizes to be used. COPYRIGHTED.

SIZE OF MAIN PIPE IN INCHES. / No. of Branch Pipes ☞	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	.758	.644	.574	.525	.488	.459	.435	.415	.398	.383	.370	.358	.348	338	.330
$1\frac{1}{4}$	.985	.838	.747	.683	.635	.597	.556	.540	.518	.498	.482	.466	.452	.440	.428
$1\frac{1}{2}$	1.14	.967	.861	788	.733	.689	.653	.623	.597	.575	.555	.538	.522	508	.494
2	1.52	1.29	1.15	1.05	.977	.918	.870	830	.796	.766	.740	.717	.696	.677	.660
$2\frac{1}{2}$	1 89	1.61	1.44	1.31	1.22	1.15	1.09	1.04	.995	.958	.925	.896	.870	.846	.825
3	2.27	1.92	1.72	1 58	1.47	1.38	1.31	1.25	1.19	1.15	1.11	1.08	1.04	1.02	.989
$3\frac{1}{2}$	2.65	2.26	2.01	1.84	1.71	1.61	1.52	1.45	1.39	1.34	1 30	1.25	1.22	1.18	1.15
4	3.03	2.58	2.30	2.10	1.95	1 84	1.74	1.66	1.59	1.53	1.48	1.43	1.39	1.35	1.32
$4\frac{1}{2}$	3.41	2.90	2.58	2.36	2.20	2 07	1.96	1.87	1.79	1.72	1.67	1.61	1.57	1.52	1.48
5	3.79	3.22	2.87	2.63	2.44	2.30	2.18	2.08	1.99	1.92	1.85	1.79	1.74	1.69	1.65
6	4.55	3.87	3.45	3.15	2.93	2.75	2.61	2.49	2.39	2.30	2 22	2.15	2.09	2 03	1.98
7	5.30	4.51	4.02	3.68	3 42	3.21	3.05	2.91	2 79	2.68	2.59	2.51	2.44	2.37	2.31
8	6.06	5.16	4.59	4.20	3.91	3.67	3.48	3.32	3.18	3.09	2.96	2.87	2.78	2.71	2.64
9	6.82	5.80	5.17	4.73	4.40	4 13	3.92	3.74	3.58	3.45	3.33	3.23	3.13	3.04	2.97
10	7.58	6.44	5.74	5.25	4.88	4.59	4.35	4.15	3.98	3.83	3.70	3.59	3.48	3.38	3.30
12	9.09	7.73	6.89	6 30	5.86	5.51	5.22	4.98	4.78	4.60	4.44	4.30	4.18	4.06	3.96
14	10.6	9.02	8.04	7.35	6.84	6.43	6.09	5.81	5 57	5.36	5.18	5.02	4.87	4.74	4.62
16	12.1	10.3	9.19	8.40	7 81	7.35	6.96	6 64	6.37	6.17	5.92	5.74	5 57	5.42	5.28
18	13.6	11.6	10.3	9.46	8.79	8.26	7 84	7.48	7.17	6.90	6.66	6.45	6.26	6.09	5.94
20	15.2	12.9	11 5	10.5	9.77	9.18	8.70	8.30	7.96	7.66	7.40	7.17	6.96	6.77	6.60
22	16.7	14.2	12.6	11.6	10.7	10.1	9 58	9.14	8.76	8.43	8.14	7.89	7.66	7.45	7.26
24	18.2	15.5	13.8	12 6	11.7	11.0	10.4	9.97	9.55	9.20	8.88	8.60	8.35	8.12	7.92

Requirements of Rock Drills.

The speed of the Drill, the pressure of air and the nature of the rock, affect the consumption of power by Rock Drills.

A three inch Drill using air at 30 lbs. pressure made 300 blows per minute and consumed the equivalent of 64 cubic feet of free air per minute. The same drill with air of 58 lbs. pressure made 450 blows per minute and consumed 160 cubic feet of free air per minute.

Drill makers differ very much in their own statements regarding the amount of air required for the same size drill.

One maker guarantees to run with 45 cubic feet of free air per minute, and again says he requires 140 cubic feet of free air. Another places the amount from 55 to 103 cubic feet free air per minute. At Hell Gate different machines doing the same work used from 80 to 150 cubic feet free air per minute.

Stops to change Drills give opportunities for the Compressor to store air in the reservoir, and where a number of drills are used it is generally safe to reckon on the average consumption of air.

An average consumption may be taken generally from 80 to 100 cubic feet per minute, according to the nature of the work.

There is no economy in restricting the quantity or pressure of air for the Drills. The limit is only reached when the drill point dulls too rapidly. The wages of the Drill runner is a more important item than the cost of compressing the air for his drill.

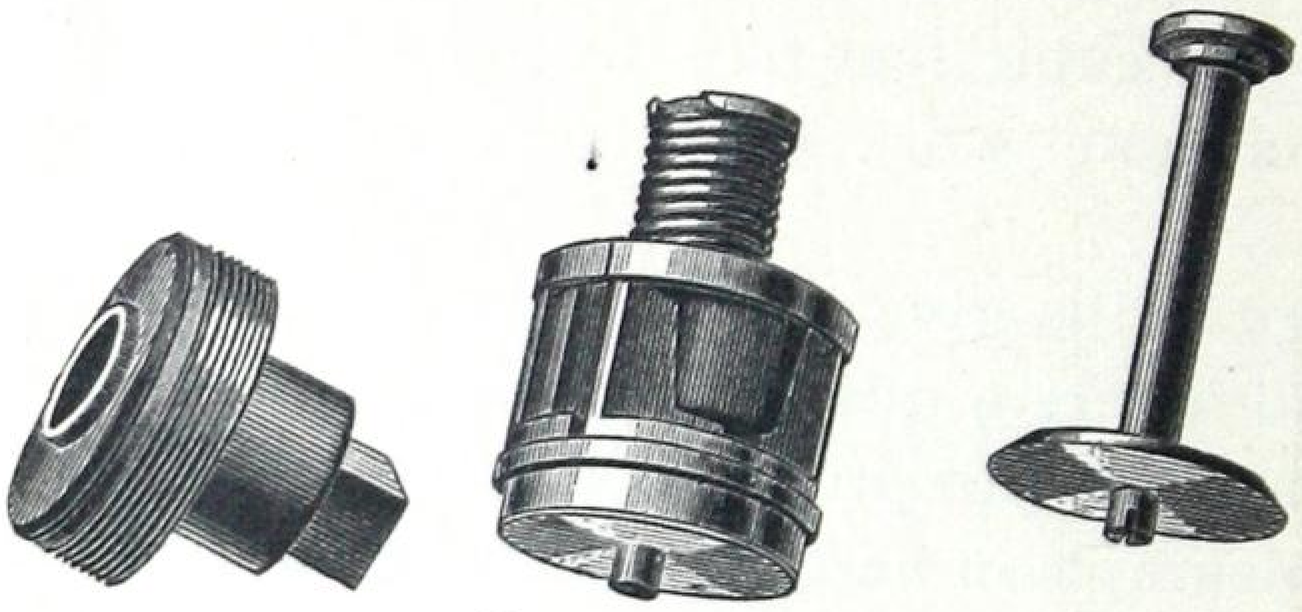
Mine operators in purchasing an outfit should remember that the Compressor is the most important matter for them to decide. It is a machine to be erected on a permanent foundation, and when once erected the success of the entire plant depends upon it. It should be capable of compressing to at least 100 lbs. pressure or even higher if the drill steel will stand the work. It should be well calculated for long and continuous work, night and day. Unless we particularly specify otherwise, at the time of making a statement regarding the number of drills a certain compressor will drive, we intend to state the number which can in the ordinary way be kept satisfactorily employed on the work. Frequently the number can be increased, and on the other hand if all the drills should purposely be run at the same instant it might carry the pressure a little lower than the desired limit. These differences are due to the character of the work and the skill, or want of skill, of the drill runner. Capacities of compressors can be guaranteed, but *exact* consumption of air by drills can be stated only when definite methods of running be agreed on.

Rock Drills are little more than shelf hardware, and can be purchased on call in any quantities. Frequently several patterns of Drills are introduced at once on the same work for the purpose of ascertaining the pattern which is best adapted for that particular service. Such a course will give an operator a valuable experience as to different Drills. It may change opinions previously formed and frequently leads to the final adoption of a different make than was originally selected.

Air Compressors for Light Pressures.

PATENTED.

We illustrate on the opposite page a compressor intended for light air pressures or for such pressures as any non-compound or single air cylinder compressor is suitable. The machine can be erected on either a vertical or horizontal position. The illustration shows it in vertical position, being clamped to a post. The post is by choice made of a length of large steam or gas pipe and extends from floor to ceiling. This hollow column makes a very convenient and thoroughly sufficient compressed air reservoir. If it is desired to erect the machine in a horizontal position, the lower half of the clamps can be removed and the other portion then presents a plane surface entirely ample for the feet.



We use in this compressor a Poppet Valve of very superior construction. *The valve, valve stem and head are forged in one piece.* The significance of the above statement will be fully appreciated by engineers who have had poppet valves with stems screwed in and a nut with jam nut or split pin to serve as head of the stem. The plan of making all in one piece is an effectual cure for the skaking off of nuts and loosening stems.

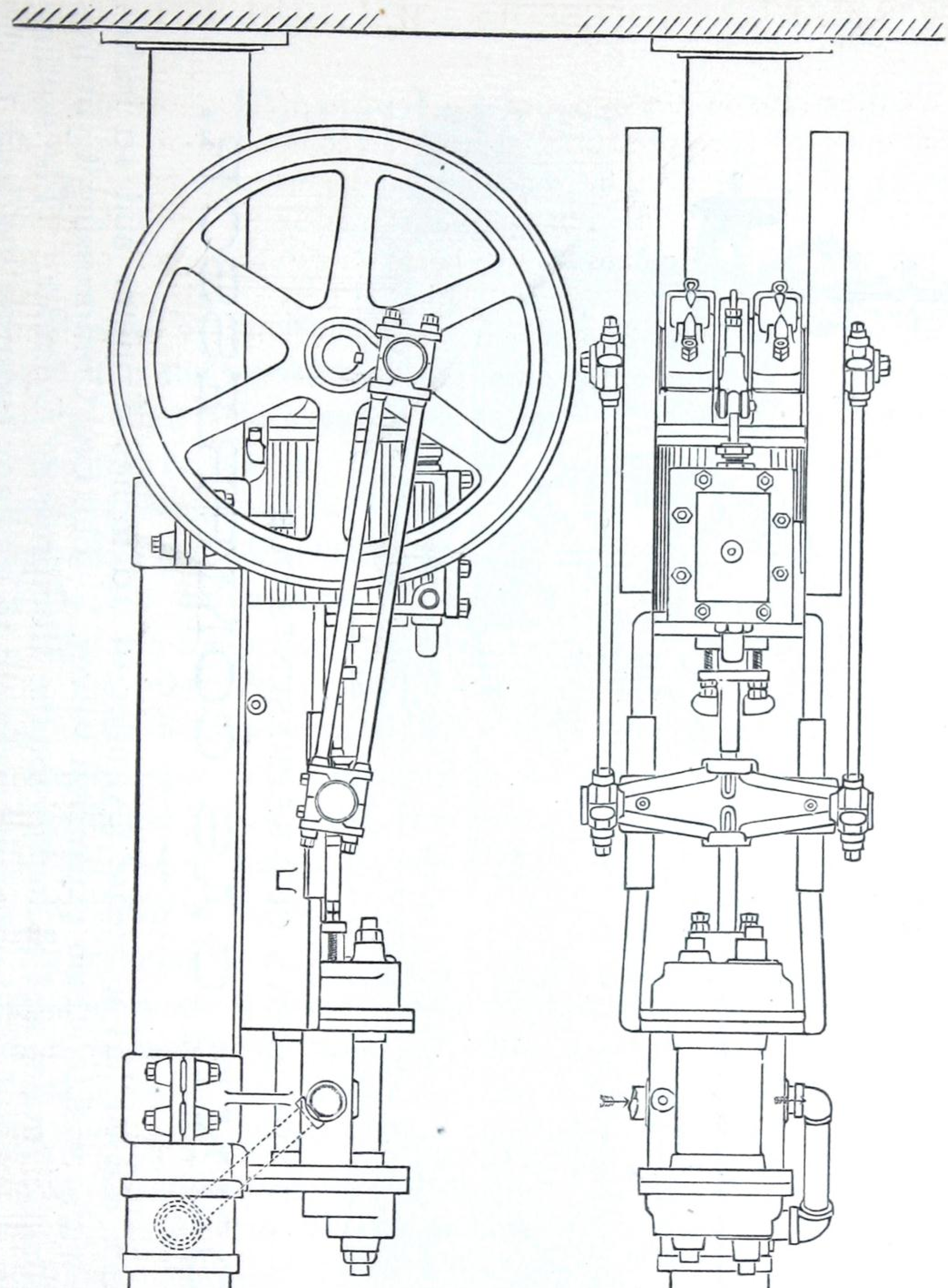
The valve spring is turned into proper position under the head as a cork-screw would be turned into a cork. The guide for valve stem fits over it in halves.

The valve seat and valve are put into the head from the outside and are secured in position by a large screw plug. The cylinder head does not require removal to get at the valves. It is the work of but a moment to take out the valves and valve seats. Being all together as a working unit their action can be investigated in the light and corrections made if needed.

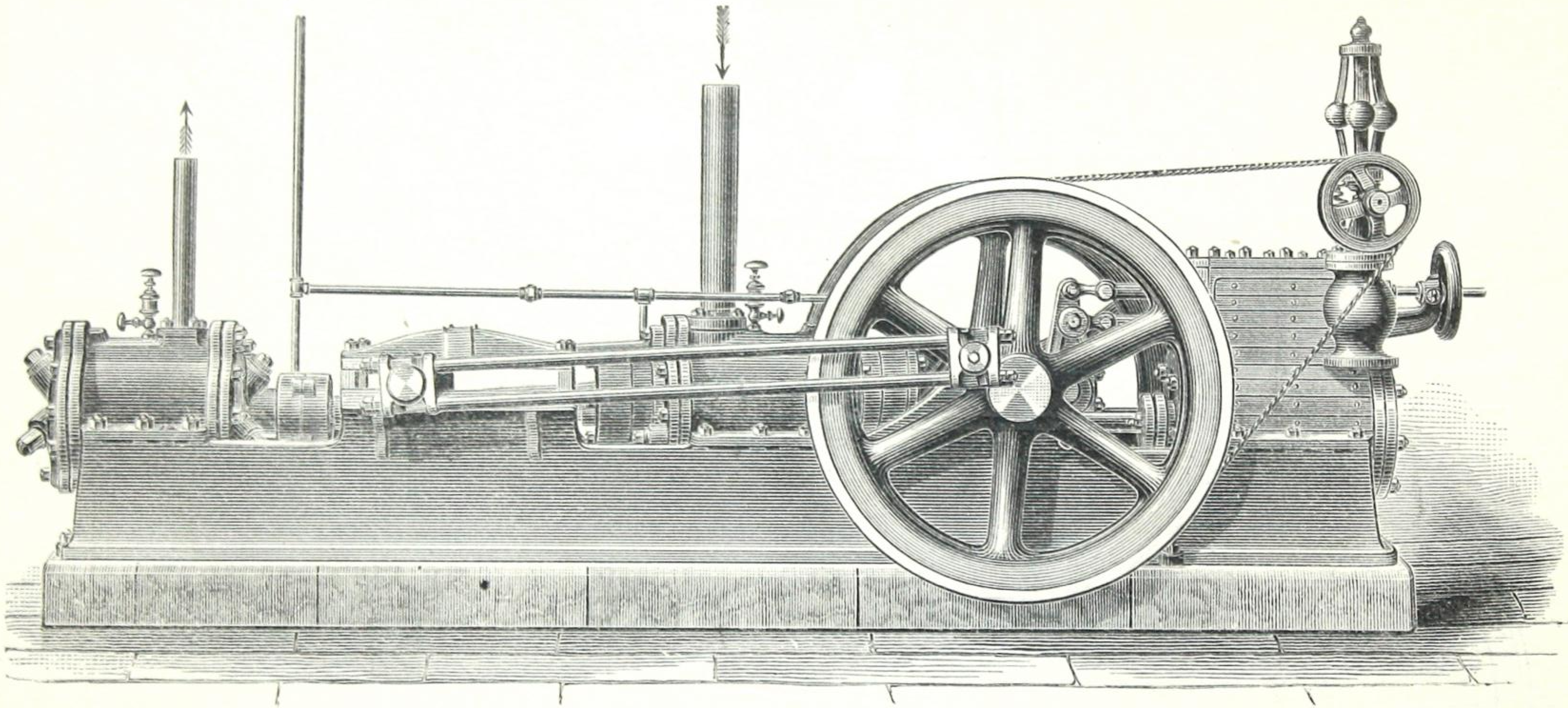
The steam cylinder of this style of compressor is 6 inches bore and 8 inches stroke. The air cylinders are varied as per the list given below:

Diameter Air Cylinder inches.	Length of Stroke inches.	Diameter of Steam Cylinder.	Revolutions per minute.	Cubic feet per minute.
6	8	6	200	52
8	8	6	200	92
10	8	6	200	145
12	8	6	200	208

Compressors for larger quantities of air at light pressures are made horizontal. In such we employ the Intake Cylinders of our Standard Compressors and combine with them steam cylinders of sizes proportioned to the work desired.



Air Compressor for Light Pressures.



THE ABOVE CUT REPRESENTS OUR

COMPOUND GAS COMPRESSOR.

The machine here shown has a Steam Cylinder of 10 inches diameter and 10 inches stroke, and is provided with variable steam expansion valves. The Gas Compressing Cylinders are 8 inches diameter for the Intake and $4\frac{1}{4}$ inches for the Compressing Cylinder. The stuffing boxes are provided with water seals, and pipes are arranged to lead any escaping gas back to the Gasometer or into the suction pipe. This size Compressor will suffice for the ordinary duty required at Railway Terminal Stations, We are prepared to furnish machines of this character of any size and for any duty.

Foundations.

The Foundation of the Norwalk Compressor is intended solely for the purpose implied by the name, that is a foundation. It is not a part of the machine but its office is to support the weight, to absorb vibration and to keep the machine in position. The Compressor is self-contained and no working strain is brought on the Foundation. This fact should be borne in mind in comparing the Norwalk Compressor with Duplex Compressors.

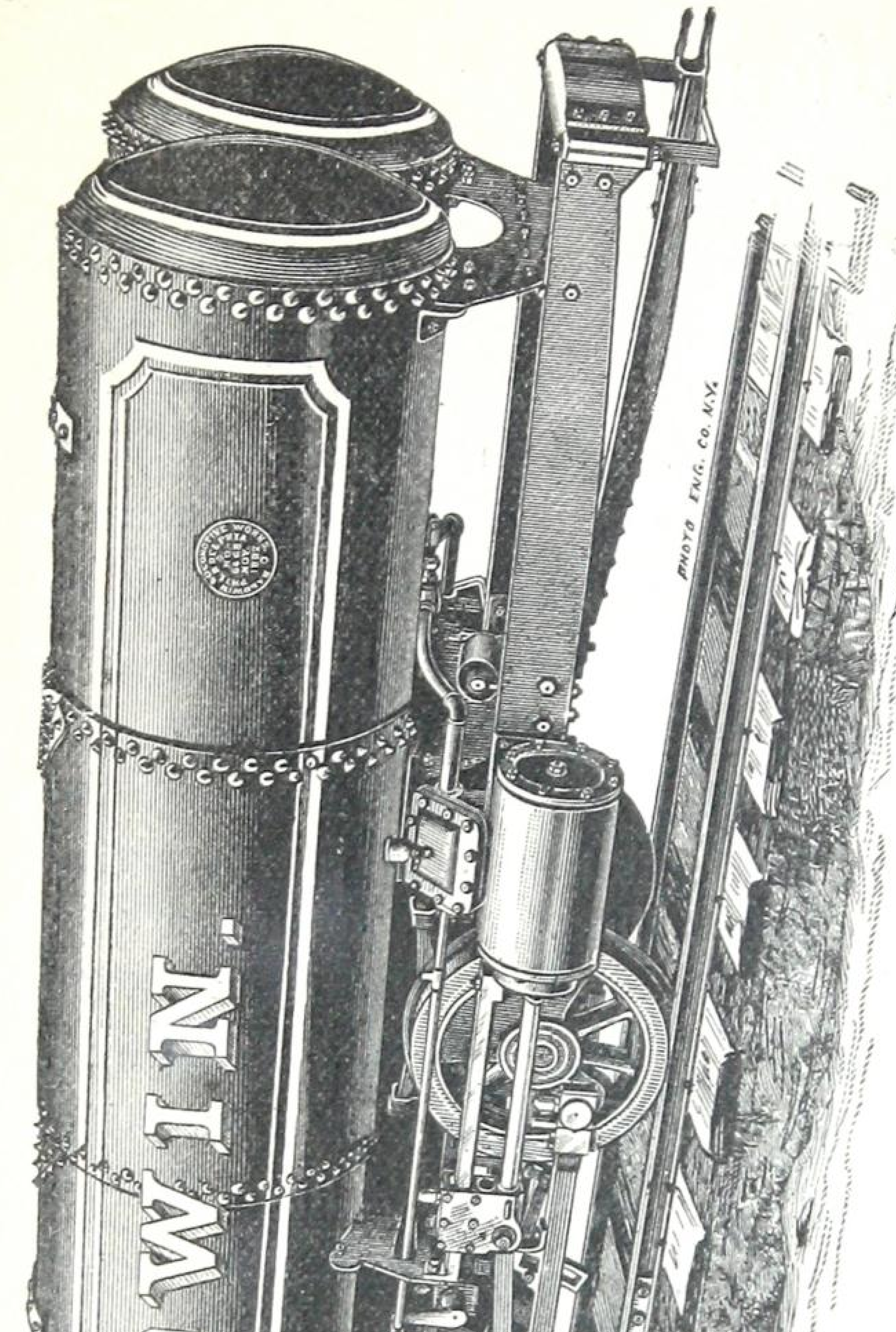
In the Duplex construction the Foundation is virtually a part of the machine. Here two compressors are placed side and side and power carried from one to the other by the heavy fly-wheel shaft. Enormous working strains come on the foundations and they must be strong enough to withstand the load. Heavy stone, cut to dimensions and carefully fitted, are required. If either Foundation should settle, very much power is then lost in friction, by reason of the heavy connecting shaft being thrown out of line. Serious results are also liable to follow.

With the Norwalk Compressor the case is very different. As has been already stated, all working strains are confined to the machine. There are no outside bearings, and hence little danger of serious trouble from a chance settling of foundation. Compressors can be set on a green foundation, can be immediately piped and set to work without waiting for foundation to "season." Any common, ordinarily good stone, suitable for country dwelling foundations, will answer for the Compressor. They should be laid in good cement and lime mortar and be well bedded.

One dimension stone on each end on top is desirable to protect ends and make a proper finish. Brick will make a good foundation if stone is not easily obtained. The Bed-Plate of Compressor should bear evenly all around the top of foundation and a joint be made with melted brimstone or iron borings. Foundation nuts should be set up hard but very evenly all around.

We have quite a number of compressors running on wooden foundations, and where timber is easier to be had than stone, we will furnish our customers drawings for timber foundations.

PNEUMATIC LOCOMOTIVES.



The Pneumatic Locomotive is destined to take the place of mules in all important works. These Locomotives are built after the same plan as ordinary mine locomotives driven by steam, with the exception that in place of a boiler a reservoir is used in which compressed air is stored to be used after the manner of steam in driving the engine. Owing to the necessarily small size of the Reservoir and the large amount of air needed for a long run, the air must be stored in the Locomotive Reservoir at a great pressure in order to have a sufficient quantity on hand. We have developed and patented a system of Reservoirs, Pipes and Special Pumps, which can be attached at comparatively slight expense to any of our Standard Compressors, and can compress the air to the high pressures needed for the Locomotives. A stationary Reservoir is provided strong enough to hold air of the pressure needed in the Locomotive. A small Compression Pump is attached to the crosshead of the large Compressor. This small pump has its supply pipe attached to the Reservoir which furnishes compressed air to the mine, and is thus supplied with air of the working pressure in the mine, usually 80 lbs. From 80 lbs. the air is compressed to the highest pressure desired, and when the limit of pressure is attained in the high pressure Reservoir, an automatic valve shuts off the supply of air to the small pump and its piston then plays in a vacuum and consumes no power. When the Locomotive is connected to be charged, then the supply pipe of the small compressing pump is connected with the high pressure Reservoir the air of the highest pressure is transferred by the pump from the Reservoir to the Locomotive. When all the air of high pressure that is desired is thus taken out of the high pressure Reservoir, then the automatic valve changes the connection of the supply pipe and air from the mine Reservoir is delivered to the small pump and the high pressure Reservoir is again charged. This plan has many advantages. It saves power, time in charging, and as much of the actual work can be done when the Locomotive is absent on a trip, a small compressing pump will do the work usually delegated to large special machines.

THE EFFICIENCY OF COMPRESSED AIR ENGINES.

THE INCREASING USE which is being made of compressed air engines, for mine and underground work, stimulates the inquiry regarding their efficiency. By the term efficiency, we mean the percentage which the power given out by the Air Engine bears to the power required to compress the air in the compressor.

THE SITUATION is apparently very simple. An engine drives an air compressor which forces air into a Reservoir. The air under pressure is led through pipes to the Air Engine and is there used after the manner of steam.

THE RESULTING POWER is frequently a small percentage of the power expended. In a large number of cases the losses are due to poor designing, and are not chargeable as faults of the system or even to poor workmanship.

THE LOSSES are chargeable, first to friction of the compressor. This will amount ordinarily to 15 or 20 per cent., and can be helped by good workmanship, but cannot probably be reduced below 10 per cent. Second, we have the loss occasioned by pumping the air of the engine room, rather than air drawn from a cool place. This loss varies with the season and amounts from 3 to 10 per cent. This can all be saved. The third loss or series of losses arises in the compressing cylinder. Insufficient supply, difficult discharge, defective cooling arrangements, poor lubrication, and a host of other causes, perplex the designer and rob the owner of power. The fourth loss is found in the pipe. This has heretofore received by no means the consideration which the subject demands. The loss varies with every different situation, and is subject to somewhat complex influences. The fifth loss is chargeable to fall of temperature in the cylinder of the air engine. Losses arising from leaks are often serious, but the remedy is too evident to require demonstration. No leak can be too small to require immediate attention. An attendant who is careless about packings and hose couplings will permit losses for which no amount of engineering skill can compensate.

WE CAN ONLY REALIZE 100 PER CENT. EFFICIENCY in the air engine, leaving friction out of our consideration, when the expansion of the air and the changes of its temperature in the expanding or air engine cylinder are precisely the reverse of the changes which have taken place during the compression of the air in the compressing cylinder. But these conditions can never be realized. The air during compression becomes heated, and during expansion becomes cold. If the air immediately after compression, before the loss of any heat, was used in an air engine and there perfectly expanded back to atmospheric pressure, it would on being exhausted have the same temperature it had before compression and its efficiency would be 100 per cent.

BUT THE LOSS OF HEAT after compression and before use cannot be prevented, as the air is exposed to such very large radiating surfaces in the Reservoir and Pipes, on its passage to the air engine. The heat, which escapes in this way, did, while in the compressing cylinder, add much to the resistance of the air to compression, and since it is sure to escape, at some time, either in Reservoir or Pipes, it is evidently the best plan to remove it as fast as possible from the cylinder and thus remove one element of resistance. Hence we find compressors are almost universally provided with cooling attachments more or less perfect in their action, the aim being to secure isothermal compression, or compression having equal temperature throughout. Where the temperature rises, without check, during compression, the term adiabatic compression is employed.

IF AIR COMPRESSED ISOTHERMALLY is used with perfect expansion and the fall of temperature during expansion be prevented, then we will have 100 per cent. efficiency. But air will grow cold on being expanded in an engine and hence we conclude that warming attachments have the same economic place on an air engine, that cooling attachments have on an air compressor. In fact we find attachments of this kind, more particularly in large and permanently located engines, but for practical reasons their use on the most of engines for mine work is dipensed with, and the engines expand the air adiabatically, or without reeeiving heat.

THE PRACTICAL ENGINEER therefore has to deal with nearly isothermal compression, and nearly adiabatic expansion, and must also consider that the air in Reservoirs and Pipes becomes of the same temperature as surrounding objects. Consideration must also be had for the friction of the compressor and the air engine. We find for the ordinary pressures, about 60 pounds which are most commonly used, that the decrease in resistance to compression, which is secured by the cooling attachments, is almost exactly equaled by the friction of the compressor. Hence it is safe in calculating the efficiency of the air engine, to consider the compressor as being without cooling attachments and also as working without friction. The results of such calculations will be too high efficiencies for light pressures, which are little used,—about correct for medium pressures which are commonly employed, and too low for high pressures, and will thus have the advantage of not being over estimated. This result is occasioned by the fact, that owing to the slight heat in compressing low pressures of air the saving of power by the cooling attachments is not equal to the friction of the machine, but at high pressure on account of the great heat the cooling attachments are of great value and save very much more power than friction consumes.

In the expanding engines, the expansion never falls as low as the adiabatic law would indicate, owing to a number of reasons, but we will consider the expansion as being adiabatic, as an error in calculations caused thereby will be on the "safe side" and the actual power will exceed the calculated. We therefore consider the compressor and engine as following the adiabatic law of compression and expansion and as working without friction.

WITH THIS VIEW OF THE CASE, the efficiency of an air engine, working with perfect expansion, stated in percentages of the power required to operate the compressor, can be placed as below for the various pressures above the atmosphere.

Pressure	above	the	atmosphere,	2.9 lbs.	94.85 per	cent.	efficiency.
"	"	"	"	14.7 "	81.79 "	"	"
"	"	"	"	29.4 "	72.72 "	"	"
"	"	"	"	44.1 "	66.90 "	"	"
"	"	"	"	58.8 "	62,70 "	"	"
"	"	"	"	73.5 "	59.48 "	"	"
"	"	"	"	88.2 "	56.88 "	"	"

We observe that the efficiences for the lower pressures are very much greater than for the high pressures, and the conclusion is almost irresistible that to secure economical results, we must design our air engines to run with light pressures. And in fact, the consideration of tables similar to the above, heretofore published by writers on this subject, has led many engineers into grave errors.

THE PIPE has been entirely neglected. We notice that a pressure of 2.9 lbs. is credited with an efficiency of 94.85 per cent. It is clear that if the air was conveyed through a pipe, and the length of the pipe and the velocity of the flow were such that 2.9 lbs. pressure was lost in friction then its efficiency instead of being 94.85 per cent. would be absolutely zero. It is therefore the power, which we can get from the air after it has passed the pipe and loss a part of its pressure by friction, that we must consider, when we state the efficiency of our entire apparatus.

OUR TABLE OF EFFICIENCIES with a loss of 2.9 lbs. in the pipe, now gives us different values for the efficiencies at the various pressures.

Pressure above the atmosphere,	2.9 lbs.	00.00 per cent. efficiency.
" " " "	14.7 "	70.44 " "
" " " "	29.4 "	68.81 " "
" " " "	44.1 "	64.87 " "
" " " "	58.8 "	61.48 " "
" " " "	73.5 "	58 62 " "
" " " "	88.2 "	56.23 " "

It will be noticed that the light pressures have lost most by the pipe friction; 2.9 lbs., having lost 100 per cent.; 14.7 lbs. 11 per cent. and 88.2 lbs. only a trifle over one-half of one per cent. We see that now 14.7 lbs. is apparently the economical pressure to use. But a further careful analysis of the subject shows, that when the loss in the pipe is 2.9 lbs., then 20.5 lbs. is the most economical pressure to use and that the efficiency is 71 per cent. But 2.9 lbs. is a very small loss between compressor and air engine, and cases are extremely exceptional where the friction of valves, pipes, elbows, ports, &c., does not far exceed this. Yet, with these conditions, which are very difficult to fill, we see that 20.5 lbs. is the lightest pressure which should probably ever be used for conveying power, and that 71 per cent. is an efficiency scarcely to be obtained.

CONTINUING OUR INVESTIGATION and taking examples where the pipe friction amounts to 5.8 lbs., we find the following efficiencies to correspond to the stated pressure:

Pressure above the atmosphere,	14.7 lbs.	57.14 per cent efficiency.
" " " "	29.4 "	64.49 " "
" " " "	44.1 "	62.71 " "
" " " "	58.8 "	60.12 " "
" " " "	73.5 "	57.73 " "
" " " "	88.2 "	56.59 " "

We again notice that as friction increases, or in other words, when we begin to use more air and make greater demands on the carrying capacity of the pipe, then we must increase pressure very considerably to attain the most economical results. If the demands are such as to increase the friction and loss in pipe to 14.7 lbs., the air of 14.7 lbs pressure at the compressor is entirely useless at the air engine. The table will stand thus:

Pressure above the atmosphere,	14.7 lbs.	00.00 per cent. efficiency.
" " " "	29 4 "	48.53 " "
" " " "	44.1 "	55.13 " "
" " " "	58.8 "	55.64 " "
" " " "	73.5 "	54.74 " "
" " " "	88.2 "	53.44 " "

It is to be noticed that 88.2 lbs. pressure has lost only about 3½ per cent. of its efficiency by reason of as high a friction as 14.7 lbs., while the efficiency of the lower pressures has been greatly affected.

AS THE FRICTION INCREASES we see that the most efficient and consequently most economical pressure increases, In fact. for any given friction in a pipe, the pressure at the compressor must not be carried below a certain limit. The following table gives the *lowest pressures* which should be used at the Compressor with varying amounts of friction in the pipe:

2.9 lbs. friction.	20.5 lbs. at compressor.	70.92 efficiency.
5 8 " "	29.4 " "	64.49 "
8.8 " "	38.2 " "	60.64 "
11.7 " "	47.0 " "	57.87 "
14.7 " "	52,8 " "	55.73 "
17.6 " "	61.7 " "	53.98 "
20.5 " "	70.5 " "	52.52 "
23.5 " "	76.4 " "	51.26 "
26.4 " "	82.3 " "	50.17 "
29.4 " "	88.2 " "	49.19 "

So long as the friction of the pipe equals the amounts given above an efficiency greater than the corresponding sums stated in the table cannot be expected. If we should have a case which corresponded to any of these cited in the table, we could only increase efficiency by reducing the friction.

AN INCREASE IN THE SIZE OF PIPE will reduce friction by reason of the lower velocity of flow required for the same amount of air. But many situations will not admit of large pipes being employed, owing to considerations of economy outside of the question of fuel or prime motor capacity.

AN INCREASE OF PRESSURE will decrease the bulk of air passing the pipe, and in that proportion will decrease its velocity. This will decrease the loss by friction, and, as far as that goes, we have a gain. But we subject ourselves to a new loss, and that is the diminishing efficiencies of increasing pressures. Yet as each cubic foot of air is at a higher pressure and therefore carries more power, we will not need as many cubic feet, as before, for the same work. It is obvious that, with so many sources of gain or loss, the question of selecting the proper pressure is not to be decided hastily.

AS AN ILLUSTRATION of the combined effect of these different elements we will suppose a very common case.

Compressor 102 revolutions, pressure 52.8 lbs., loss in pipe 14.7 lbs., machine in mine running at 38.2 lbs., efficiency 55.73.

So long as the friction of the pipe amounts to 14.7 lbs., we have seen that 52.8 lbs. is the best pressure and 55.73 the greatest efficiency. We will reduce the friction by reducing the bulk of air passing through the pipe. We reduce the cylinder of the air engine so that it requires 47 lbs. pressure to do the same work as before. We find now the friction of pipe drops to 11.7 lbs. The pressure on the compressor rises to 58.8 lbs. its number of revolutions falls to 100 and the resulting efficiency is 57.22 per cent.

Another change of pressure on compressor to 64.7 lbs. would decrease its revolutions to 93, fraction to 8.8 lbs., and efficiency would rise to 57.94 per cent. Still again increasing pressure to 73.5 lbs. we have only 84 revolutions of compressor, 5.8 lbs. loss in pipe and efficiency of 57.73 per cent. In this last case the efficiency begins to fall off a little, and higher pressures would now show less efficiency, but, in comparison with the first example, we find we are doing the same work in the mine with a trifle less power and with a decrease of nearly 20 per cent. in the speed of the compressor.

OTHER COMMON EXAMPLES can be shown where an increase of pressure would result in wonderful increase in efficiency and economy. There are many cases where light pressures and high velocity in the pipe will convey a given power with greater economy than higher air pressures and lower speed of flow through the pipe. But these cases arise mostly when the higher air pressures become very much greater than are at present in common use.

THEREFORE IN ESTIMATING THE EFFICIENCY of the complete outfit we find that the pipe and the pressure are very important elements and must be determined with care and skill to secure the most satisfactory results. As the volume and power of air varies with its pressure, the size and consequent cost of compressor for a certain work would also be affected by the pressure. To plan an outfit for a mine due regard must be had to cost of fuel or prime motive power, and also to cost of compressor, pipes, and machinery, as the saving in one is often secured by a sacrifice in the other.

Next to determining the size of pipe, the skillful engineer has need of further care in the proper position of Reservoirs, Branches, Drains, and other attachments, as only by the exercise of good judgment in this can satisfactory work be secured.

Compressed Air Power Pumps.

The great convenience and many advantages attending the use of compressed air as the motive power in mines have brought about its introduction more rapidly than proper machinery has been produced to obtain the most economic results.

The apparent similarity between steam and compressed air of the same pressure naturally leads to the extensive employment of machinery which was primarily designed for steam. Too frequently no recognition is taken of the fact that compressed air is not steam and that it should be used in a different manner to secure the best results.

The lack of adaption is very noticeable in a great many of the pumps now used in mines and driven by compressed air. Usually these pumps were in use in the mine before the compressed air was introduced. The predominant pattern is the regular style of Direct Acting Steam Pump, without flywheels and using full pressure for the entire stroke. Such a use of steam is quite right in these situations for the reason that the slow piston speed and wet steam are powerful factors to render unavailing all attempts at economy by the employment of steam expansion.

When compressed air is used the circumstances are all favorable to its economical employment by thorough expansion. There is no condensation in pipes and cylinder, as is the case with steam, and the slow piston speed is an advantage, as is explained hereafter.

The air is admitted to the cylinder at the temperature of surrounding natural objects and as it expands in doing work it grows excessively cold. Any

addition of heat of course means an increase in power. The most available heat is the warmth of surrounding objects—for example—the water of the mine. This is readily communicated to the air by enveloping the cylinder in a water jacket.

A slow piston speed, as is necessary in pumps, now supplies a very desirable condition by allowing time for the heat to pass from the water jacket into the cold and expanding air within the cylinder. Where the temperature of the air is thus kept from falling the term isothermal expansion is used to distinguish the conditions from those of adiabatic expansion, where no heat is added to the air from without.

The gain due to expansion varies with the pressure in use, and for the purpose of comparison we append a table showing the work which can be done by air used at full pressure and expansively. The work at full pressure is expressed by 100, and the figures given in the succeeding columns express the work which will be done by the same quantity of air, used at the same initial pressure and expanded adiabatically or without receiving heat and also expanded isothermally or by receiving heat from natural objects.

Pressure				
Atmospheres.	Gauge.	Full Stroke.	Adiabatic Expansion.	Isothermal Expansion.
3	29.4 lbs.	100	142	166
4	44·1 "	100	152	185
5	58.8 "	100	161	201
6	73·5 "	100	170	217
7	88.2 "	100	172	226

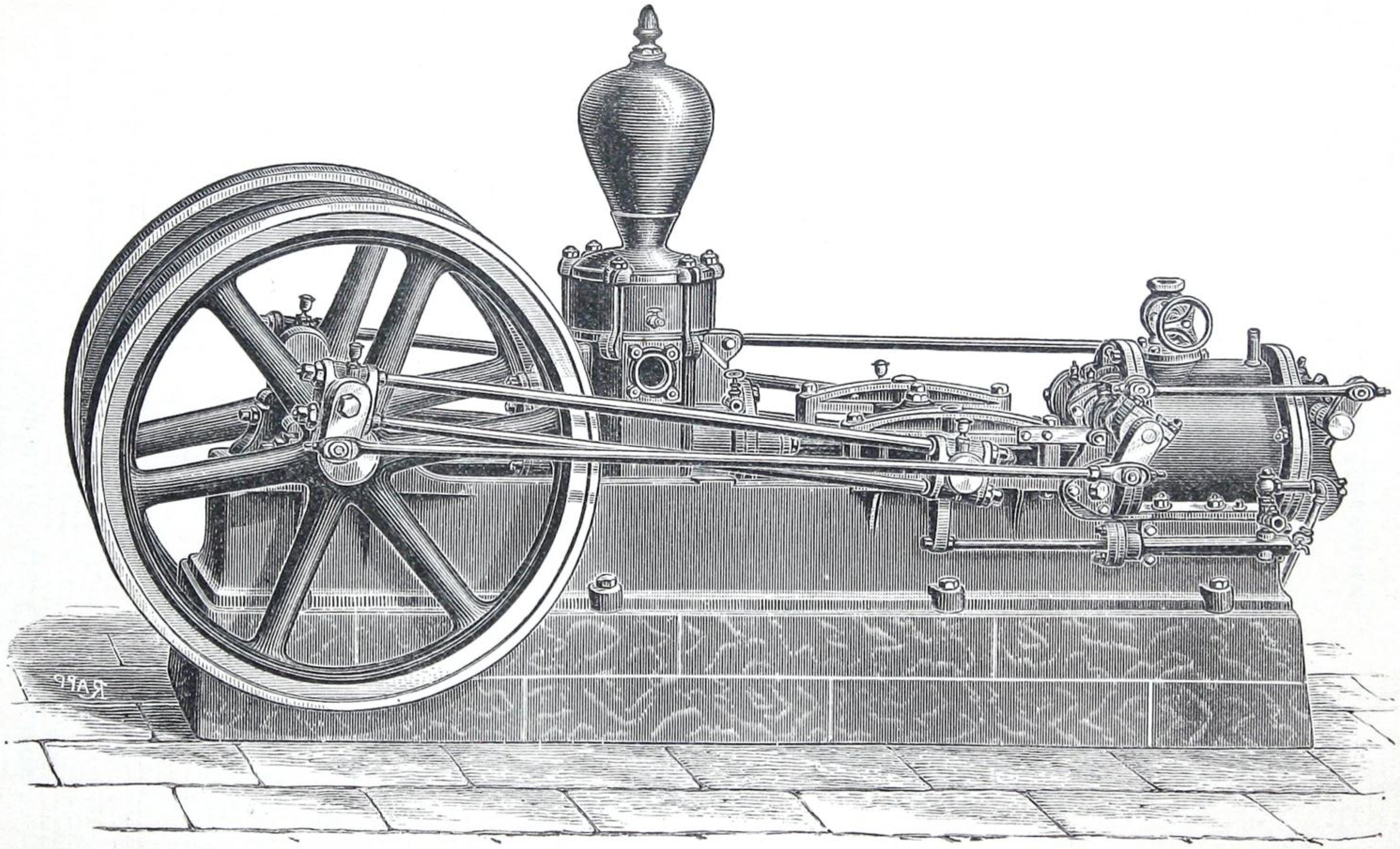
As it is practically impossible to secure the perfect transfer of heat and thus obtain exact isothermal expansion, and as it is also a matter of the greatest difficulty to so exactly proportion machines as to secure entirely perfect expansion, it will be found in practice that the actual results will be between the adiabatic and isothermal, as stated in the table above.

Such enormous gains are possible by expansion that the circumstances must be truly extraordinary that will allow these advantages to be overlooked by neglecting the proper design of the compressed air engine.

The difficulties usually met with in many air power engines are entirely obviated in this. The lubrication is perfect and no trouble is experienced by the formation of ice in the cylinder and ports.

We manufacture these machines with power cylinders of the following sizes:—10"x12", 14"x16" 20"x24", 26"x30".

The Water Cylinders are proportioned for the work desired—a statement of which we require.



We illustrate a Pump designed to be driven by compressed air and intended to utilize the advantages of isothermal expansion as described above. The cylinder is surrounded by a water jacket through which the water of the mine is pumped. The temperature of this water is always very many degrees above the temperature of the expanding air within the cylinder and hence the water jacket becomes an efficient heater.

Corliss Valves are used both for admission and exhaust, and are placed in the cylinder heads thus reducing the clearance space to a minimum. The point of cut-off can be varied to suit the requirements of each particular situation.

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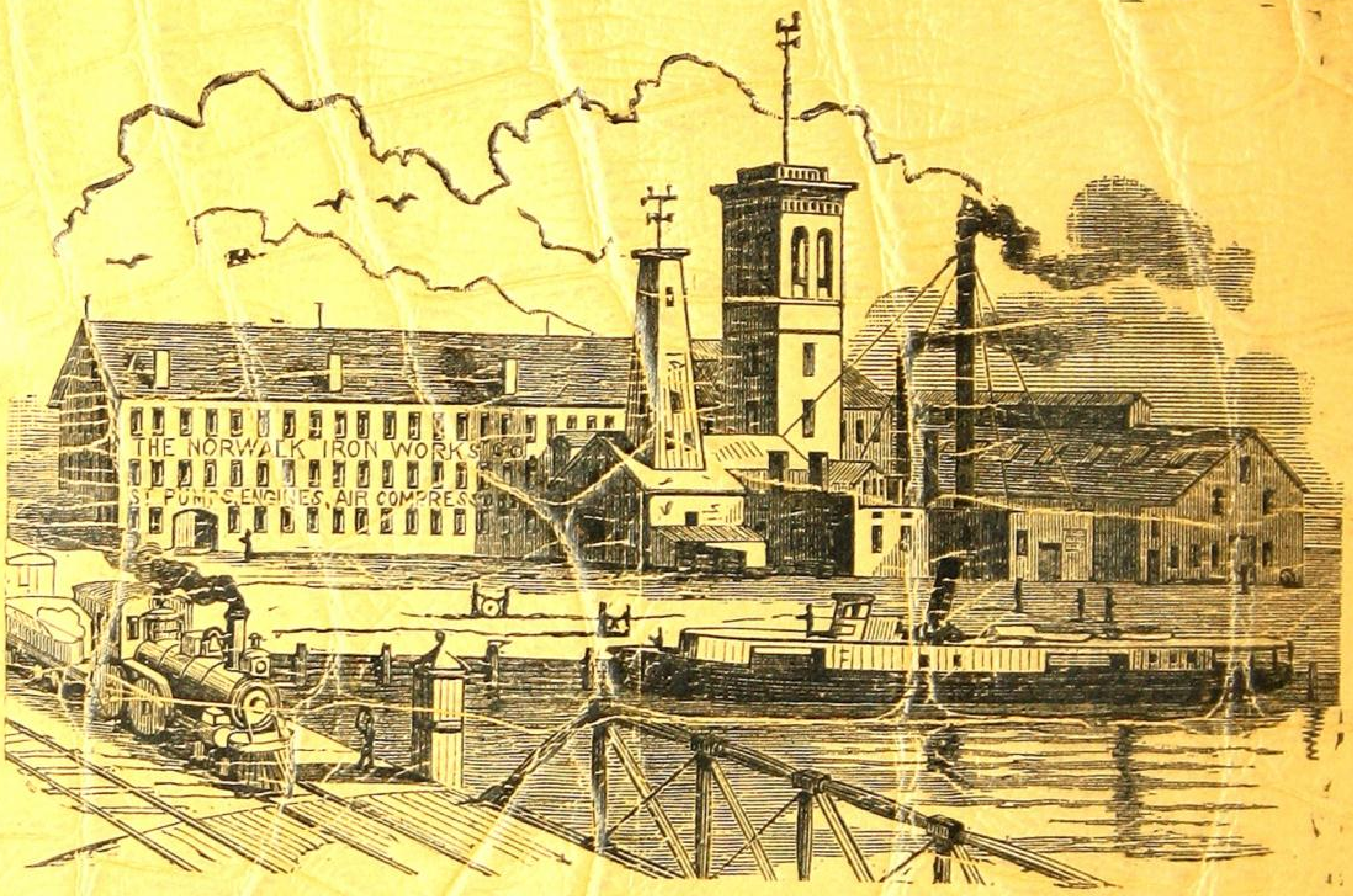
INTERNATIONAL



Harbor View of the Works of the Norwalk Iron Works Co.

Evening Sentinel Print, South Norwalk.